# Changes in strength and power characteristics over a season in elite English rugby union players

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Thesis submitted for MSc (by research)

By

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## Declaration

I declare that this thesis is my own work. It is being submitted for the degree of MSc by Research at the University of Bedfordshire. It has not been submitted for any degree or examination in any other University or educational institute.

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## List of abbreviations

| | |
|---|---|
| CMJ | Countermovement jump |
| CK | Creatine kinase |
| DJ | Depth jump |
| EUR | Eccentric utilization ratio |
| FFM | Fat free mass |
| IMTP | Isometric mid-thigh pull |
| RFD | Rate of force development |
| RFU | Rugby Football Union |
| RSI | Reactive strength index |
| SSC | Stretch shortening cycle |
| SQJ | Squat jump |

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**Abstract**

Those involved in the physical preparation of elite players must balance the stresses of training multiple physical qualities with the need to adequately recover and perform optimally on a weekly basis over a long competitive season (Brooks *et al.*, 2005). At present limited information exists regarding the changes in strength, power and body composition that occur during the pre-season and competitive season in elite rugby union players. It is currently unclear how neuromuscular characteristics such as rate of force development (RFD), stretch shortening cycle performance and maximal force production change over a season. Furthermore the effects of both positional grouping of players and game time exposure on the change in physiological characteristics in professional rugby union players remains to be elucidated.

The purpose of this investigation was to determine the change in strength, power and body composition in 19 male, English professional rugby union players over the course of a 41 week season, consisting of an eight week pre-season and a 33 week competitive season. The subject group consisted of 5 backs and 14 forwards from the same RFU Championship division team. Subjects participated in four data collection sessions in which body composition data were obtained followed by jump and isometric mid-thigh pull (IMTP) testing. Changes in physiological characteristics were examined and the relationships between these and game minutes played were explored.

Increases of 6.9% in IMTP peak force were observed following the pre-season alongside decreases of -10.9% and -1.8% in RFD at 0.1 s and eccentric utilization ratio (EUR) respectively. Increases of 4.5% in IMTP peak force, 17.8% in RFD at 0.1 s and 2.8% in EUR were observed over the competitive season. An improvement of 1.7% was observed in fat-free mass (FFM) alongside a 1.3% reduction in body mass during pre-season. Following this FFM was maintained whilst body mass showed a small increase (1.7%) over the competitive season. The two positional groups followed a similar pattern of change throughout the whole season although backs showed larger decreases in reactive strength index and IMTP force at 0.1 s following the pre-season period. A moderate correlation was found between total minutes played and increases in IMTP peak force ($r = 0.36$, $p = 0.07$) whereas small ($r = \leq 0.19$, $p = \geq 0.19$) or small negative correlations ($r = \geq -0.23$, $p = \geq 0.18$) were reported between total match minutes and change in power based measures

The results of this investigation show strength can be improved over the pre-season and competitive season in elite English rugby union players. In contrast power based characteristics are likely to decrease over the pre-season period and be maintained or show small increases during the competitive season. Whilst both positional groups are likely to show similar changes in physiological characteristics, fast SSC performance may be affected to a greater degree in backs. High match exposure does not impair strength development but may impact negatively on the development of some power based characteristics.

Key words: Rugby union, strength, power, rate of force development, stretch shortening cycle performance, fatigue, body composition

# *Chapter 1:*

# *Introduction*

## 1.1 Introduction

Rugby union is an intermittent, high intensity team sport played in many countries. It is characterised by frequent physical contacts and maximal accelerations interspersed with periods of low intensity activity (Duthie, Pyne and Hooper, 2003). Rugby union requires well developed sport specific, technical and tactical skills as well as a combination of physical attributes including strength, power, agility, speed, aerobic and anaerobic endurance. Since rugby union became a professional sport in 1995, the speed, power, strength and body composition of players has evolved rapidly and as a result the speed and physicality of matches has increased (Duthie, Pyne and Hooper, 2003, Van Rooyen *et al.*, 2008). The commercial demands of professionalism have also lead to an increased number of fixtures for elite players (Quarrie and Hopkins, 2007). The need for players to compete more frequently in more physically demanding fixtures has led to increased interest in optimising physical preparation for rugby.

High levels of strength and power have been described as crucial to competing in rugby union at the elite level (McMaster, McGuigan and Gill, 2015). Furthermore, differences in these qualities have been shown to distinguish between performance levels of players in similar team contact sports such as rugby league and American football (Fry & Kraemer, 1991, Baker, 2002). Within rugby union it is likely that stronger, more powerful players will be more effective within the aspects of the game involving physical contact between opponents such as in the tackle contest or at the breakdown (Argus, 2012). Stronger, more powerful players are also likely to possess superior speed and acceleration capabilities versus less strong counterparts (Baker and Nance, 1999, Barr *et al.*, 2014, Sietz *et al.*, 2014).

Within a team rugby union players can be divided into two distinct positional groups, namely backs and forwards. Studies examining player characteristics have shown that forwards are generally taller, heavier and possess greater levels of body fat than backs (Bell, Cobner and Eston, 2005). In contrast backs are generally faster with superior sprinting and jumping ability (Smart *et al.*, 2014). Clear differences between these groups have also been reported in terms of activity profiles within matches (Quarrie *et al.*, 2013). Forwards generally perform more force dominant tasks such as scrummaging, rucking, and mauling whereas backs perform more velocity dominant tasks such as sprinting, high speed direction change and kicking (McMaster, McGuigan and Gill, 2015). Optimising position specific force development represents a training priority for both groups. In order to maximise levels of strength and power, players undergo resistance training throughout the year (Sykes, 2015). Players also carry out resistance training with the objective of increasing fat free mass (FFM) (Appleby, Newton and Cormie, 2012, Baker, 1998). A greater FFM has been shown to be associated with increases in strength and power in elite rugby players and is likely to be beneficial in increasing impulse within collisions (Corcoran, 2010, Waldron *et al.*, 2014).

Rugby union players generally follow an annual periodized training programme based around a pre-season, a competitive season and an off-season (Sykes, 2015). The pre-season typically lasts between 4 and 12 weeks (Argus *et al.*, 2010) and will often be designed to bring about significant changes in key physical characteristics. The pre-season phase typically incorporates a far higher volume and intensity of sessions aimed to bring about improvements in strength, power, speed and aerobic, and anaerobic endurance. Given that the adaptive remodelling of muscle tissue will only take place given sufficient stimulus, time and resources (Peterson, Rhea and Alvar, 2005) practitioners must balance the need to improve physiological capacities with the need to recover in the pre-season. During the competition phase, players are likely to play matches every 5 to 9 days (Mclean *et al.*, 2010) and as such training in this period is likely to focus on combining the maintenance of physical qualities with the need to perform optimally each week (Sykes, 2015). Competition phases within English rugby union often last in excess of 30 weeks (Brooks *et al.*, 2005). In both the pre-season and competitive season it is essential that coaches deliver the correct training type, frequency and load to ensure physical development or maintenance without accumulation of residual fatigue and decreased competition performance.

In order to prepare players optimally for competition practitioners need to understand what level of strength and power is required for performance in professional rugby union (Argus, 2012). Practitioners also need to understand how the different phases of the season are likely to affect player levels of strength and power. Whilst a great deal of work has investigated the responses of the neuromuscular system to resistance training much of this has examined changes in untrained or inexperienced participants over relatively short periods (Baker, 2001). Such work is obviously of limited relevance to professional rugby union, not least as it fails to replicate the demands of rugby in terms of the quantities of concurrent training players must perform (Argus, 2012). It is important for those involved in training prescription within rugby union to understand which factors are likely to affect the direction and magnitude of change in players' physiological characteristics during both the pre-season and competitive season. Whilst many studies have examined normative levels of strength and power within rugby league and union (Baker and Newton, 2008, Comfort *et al.*, 2011, West *et al.*, 2012) very little work has looked at changes in physiological characteristics over the pre-season phase or competitive season in rugby union players (Argus *et al.*, 2009, Argus *et al.*, 2010). Although several studies have investigated changes in physiological characteristics in other contact codes of football, differences between these studies in terms of pre-season and competitive season lengths, subject characteristics and testing methods make clear conclusions hard to draw. Furthermore, no studies have examined such changes in rugby union players playing in English professional competitions. In addition to this whilst the volume of games played per season is known to influence fatigue (Hartwig, Naughton and Searle, 2009) very little is known regarding the influence of game time on the change in physiological characteristics during the competitive season (Gabbett, 2005a; 2005b). There is also very little evidence concerning changes in neuromuscular characteristics likely to underpin the performance of power based tasks over a competitive season. Differences in the way in which physiological characteristics change based on positional groups are also unclear. Given the increased focus on physical preparation within rugby union it is vital that practitioners have an understanding of likely changes in physiological characteristics across a season and the factors likely to influence such changes.

## 1.2 Aims

In light of gaps in the literature regarding change in physiological characteristics in professional rugby union players in England the aims of this thesis are as follows;

- To examine changes in strength, power and body composition over the pre-season and competitive season in professional rugby union players based in England.
- To investigate whether there is a difference in the magnitude or direction of change based on positional group.
- To identify the effect of game time on changes in physiological characteristics during the competitive season.

## 1.3 Research Questions and Experimental Hypotheses

The aims will be achieved through answering the following research questions;

- In what direction and to what magnitude do levels of strength, power and body composition change in professional rugby union players playing in English competition change over the pre-season and competitive season?
- To what extent are changes in physiological characteristics influenced by positional group?
- Is there a relationship between the quantity of game time players are exposed to and the direction or magnitude of changes in physiological characteristics?

It is hypothesised that;

$H_1$- The pre-season phase will coincide with increases in strength, decreases in power and improvements in body composition.

$H_2$- During the competitive season levels of strength and power will be initially maintained before showing small decreases towards the end of the season. Body composition will deteriorate across the competitive season. Considerable individual variation in change in all qualities will be evidenced.

$H_3$- There will be little difference in change in physiological characteristics between positional groups over the pre-season. Forwards will maintain strength over the competitive season whereas backs will reference small decreases. Backs will however maintain power whereas forwards will not. Change in body composition will not differ by positional group.

$H_4$- Game time will be related to change in strength, power and body composition in a negative manner. Those players playing the highest game minutes across the competitive season will show significant reductions in strength, power and FFM.

# *Chapter 2:*

# *Literature Review*

## 2.0 Literature Review

### 2.1 Introduction

Elite rugby union players are often required to compete weekly over long competitive seasons regularly experiencing high levels of neuromuscular fatigue and muscle soreness (Mclean *et al.*, 2010, Takarada, 2003). Given that decisive games with large commercial consequences often take place at the end of the season it is vital that key physical qualities are maintained throughout a competitive season. Those involved in physical preparation must therefore strike a difficult balance between training to improve performance capacities and providing adequate rest and recovery to ensure optimal performance on a weekly basis. In order to understand how best to prepare their athletes, conditioning practitioners within rugby union must understand how key physiological characteristics such as strength and power are likely to change over a full season and which factors are likely to effect the development or maintenance of such qualities.

This literature review examines studies reporting changes in strength, power and body composition over the course of a season. Within rugby the season is typically divided up using a phasic model of periodization based around an off-season, a pre-season and a competitive season (Sykes, 2015). The off-season has been defined as a period of the year combining active rest and individual preparation prior to the start of scheduled technical and tactical training (Gamble, 2006). The pre-season involves concurrent technical and tactical practice and features a high intensity regime of physical training targeting multiple, rugby related components of fitness (Argus, 2012). There will often be progressively more match like practices and this period may feature some full matches which are outside the clubs competitive league or cup fixtures. For clarity, the competitive season can be considered the period of the year where the team are actively involved in league or cup fixture schedules. It is likely to feature frequent competition and a reduction on conditioning volume (Gamble, 2006). This review will examine studies reporting changes in the pre-season period, the competitive season and across periods of time representing multiple seasons.

## 2.2 Changes in Physiological Characteristics

### 2.2.1 Maximal Strength

Maximal strength has been defined as the capacity of a muscle to actively develop force (Argus, 2012). It has most commonly been assessed in rugby players via one to three repetition maximum tests in the deadlift, squat and bench press exercises (McMaster *et al.*, 2014). Whilst such measures are useful in an applied setting, given that the hyperbola describing the relationship between force and velocity of contraction in skeletal muscle shows peak forces occur in eccentric or isometric conditions (Hill, 1938) it is clear such exercises do not measure maximal strength per se. When reporting maximal strength most of the studies examined are in fact assessing high load, low velocity force production through resistance training exercise (Cormie, McGuigan and Newton, 2011b). For the purpose of this review the term maximal strength is therefore used to describe performance within high load, low velocity tasks (Sunde *et al.*, 2010). Within rugby union such high force, low velocity output is required for activities such as scrummaging and mauling. Maximal strength has also been shown to be of great importance to rugby union performance as it is an underpinning quality of other key physiological characteristics in rugby union such as power, speed and agility (Sietz, 2014).

#### 2.2.1.1 Pre-season changes in maximal strength

Several studies have focused on the changes in maximal strength occurring during the pre-season phase in the contact codes of football (Appendix 5, Table 6.1). To date only one study has examined maximal strength changes in professional rugby union players over the pre-season period. Significant improvements in lower-body and upper-body maximal strength measured via deadlift or concentric squat and bench press performance respectively have been reported following a pre-season phase in elite rugby league players (Harris *et al.*, 2008, O'Connor and Crowe, 2007, Rogerson *et al.*, 2007). It should however be noted whilst many similarities between rugby league and rugby union exist there are also key differences in terms of distances covered during a match, work to rest ratios and time spent at maximal intensity (Gabbett, 2005c, Duthie, Pyne and Hooper, 2003). Such differences in match play are likely to affect both pitch and gym based training. When combined with the greater homogeneity of physiological characteristics of rugby league players compared to those in rugby union (Gabbett, 2015) it appears it is perhaps not always appropriate to directly compare the findings in one code of rugby to another. In rugby union, Argus *et al.* (2010) reported an increase in lower and upper body maximum strength over a 4 week pre-season in professional players. These authors reported an 11% increase in both maximal box squat and bench press performance. However, given the short duration of this study and the fact the subjects were from just one New Zealand based team following a different annual league structure to the northern hemisphere, it is unclear how useful these results are to a UK based practitioner. It is important to consider that this study shows the effect of one pre-season programme on one specific playing group and as a result of the numerous situational factors likely to affect the results of a particular programme (training objectives, previous training blocks, player training age and motivation) it is clear further work in this area is required.

#### 2.2.1.2 Competitive season

There is currently limited research examining changes in maximal strength over a competitive season in professional rugby union players. Without information suggesting the direction and magnitude of likely changes in maximal strength it is difficult for coaches to best plan their physical development strategy.

In college aged American football players studies have shown improvements, maintenance and reductions in both lower and upper body strength over the course of a competitive season. Fleck and Kraemer (1987) reported maintenance of lower and upper body maximal strength over the course of a competitive season. In contrast Schneider *et al.* (1998) reported an improvement in lower body muscular strength whereas Dos Remedios *et al.* (1995) and Legg and Burnham (1999) both reported reductions in strength over a competitive season in this population. It is possible that the differences in the findings between these studies may in part be due to the different testing methods employed. In assessing changes in lower body strength the study of Fleck and Kraemer measured back squat 1RM whereas in other studies both a loaded hip sled (Dos Remedios *et al.*, 1995) and a dominant limb only leg extension isokinetic dynamometry protocol (Schneider *et al.*, 1998) were used. It is likely that these tests capture different distinct strength qualities (McMaster *et al.*, 2014). Furthermore, the extent to which a dominant limb only leg extension isokinetic dynamometry protocol relates to sporting performance or bilateral isotonic or isometric assessment measures is unclear and as such must be interpreted with caution. In addition to differences in assessment techniques, a lack of information provided by these studies regarding resistance training methodologies and exposure to other training makes comparison of results very difficult.

Contrasting results regarding change in strength have also been reported over the competitive season within both codes of rugby. In rugby league increases in upper body strength have been reported in college aged players (Baker, 2001), whilst both increases and decreases have been reported in professional players (Baker, 1998, Baker, 2001). Only Baker (1998) has examined changes in lower body maximal strength during a competitive season in professional rugby league players. This study reported a 3% improvement in back squat 1RM over the course of 22 weeks. In rugby union Argus *et al.* (2009) reported an increase in lower body maximal strength measured via 1RM box squat of 8.5% across a 13 week competitive season. This study also reported a small decrease in upper body maximal strength measured via maximal bench press performance (-1.2%). Argus *et al.* (2012) reported a 4.8% increase in lower body maximal strength following a 4 week power development phase during a competitive season in rugby union players. The short duration of this study and the fact it was the first 4 weeks of the competitive season however limit the usefulness of these findings in explaining strength change across a competitive season.

A key difference between the studies within rugby football which may explain some of the discrepancies within the findings is the length of competitive season examined. The studies presented here look at in-season periods ranging from 4 to 29 weeks. Greater competition exposure over a longer competitive season is likely to lead to higher levels of cumulative fatigue and increased risk of injury and resulting training modification. Both of these factors have been proposed to cause performance decreases (Hyrosamilis, 2010). Based on the work of Argus (2012) a longer competitive season of 15 weeks or more is likely to result in only the maintenance of strength (0% ± 6%) whereas strength can be improved across a shorter competitive season period of less than 15 weeks (3% ± 5%).

The contrasting findings of studies within the contact codes of football make clear conclusions regarding strength change during the competitive season difficult to draw. Furthermore, with only one study investigating strength change over a whole season in rugby union players it is difficult for the practitioner to have a clear picture of the likely direction and magnitude of strength change over a competitive season in rugby union. In addition to this given the duration of the season examined in this study is less than half of that typically seen in professional English competitions (Brooks *et al.*, 2005) it is unclear how rugby union players' strength characteristics are likely to change across a much longer competitive season. As previously mentioned greater match exposure may lead to increased fatigue and therefore greater decrements in physiological variables. This however remains to be elucidated.

Several studies have examined the longer term development of maximal strength in elite rugby players in both codes of rugby (Appendix 5, Table 6.3). Improvements in both upper and lower body strength over periods of between 2 and 6 years have been documented (Appleby, Newton and Cormie, 2012, Baker and Newton, 2006). However whilst these studies show a general trend of strength increase over multiple seasons, the way in which strength was measured either annually or pre and post a multi-year training period represents a limitation in explaining likely changes in strength over a long competitive season. Without knowing the likely magnitude and direction of strength change over a season it is difficult for practitioners to prepare optimal strategies to maintain or develop physiological characteristics important to success in rugby union.

Differences in the strength tests employed in the studies examined here are likely to explain some of the differences in findings. Whilst the squat, deadlift and bench press 1RM tests are commonly used to assess maximal strength (McMaster *et al.*, 2014) differences in protocols used in the studies examined here are likely to affect results. Within the squat, variations in depth and whether or not subjects squatted to a box are known to affect the kinematics in terms of specific joint moments and therefore, potentially the resulting strength scores (Swinton *et al.*, 2012). Investigations examining the deadlift have also shown that the muscles of the core, arms, shoulders, and upper back are greatly activated due to the need to stabilize the body and grip the bar (Noe *et al.*, 1992). It is therefore possible that increases in deadlift 1RM could occur without improvements in maximal lower body force production per se. It has been suggested that due to training and competition loads rugby players are exposed to, the isometric mid-thigh pull (IMTP) test may represent the best means of assessing a player's strength progression (West *et al.*, 2011). IMTP performance has been shown to be strongly correlated to maximum dynamic strength (Blazevich, Gill and Newton, 2002). It also allows strength at joint angles specific to sporting performance to be examined (Kawamori *et al.*, 2006) and provides information regarding the temporal characteristics of an athlete's maximum force development. Despite this no study has examined the change in strength via the IMTP across a pre-season or competitive season in rugby.

The relationship between force and velocity previously eluded to (p.8) shows that levels of maximum force production will in part determine force generation at a given velocity of muscular contraction (Cormie, McGuigan and Newton, 2011a). Whilst strong relationships have been reported between maximum strength and maximum power output (Moss *et al.*, 1997), it appears that increases in power production as a result of strength training are likely to occur in relatively untrained or weaker subjects (Cormie, McGuigan and Newton, 2010). It is however currently unclear if this relationship holds across a season in elite rugby players and how the relationship is affected by levels of fatigue likely to result from frequent match play (Hyrosamilis, 2010).

### 2.2.2 Muscular Power

From an applied perspective, muscular power can be defined as the highest level of work that can be performed per unit time in a single movement with the goal of maximising velocity (Newton and Kraemer, 1994). It is required for all rugby union movements in which high force must be applied quickly such as accelerating, cutting and tackling. Maximal power production has been described as a multifaceted quality which is influenced by numerous neuromuscular components such as muscle and tendon morphology, stretch shortening cycle (SSC) performance, rate of force development (RFD) and low and high velocity strength (Cormie, McGuigan and Newton, 2011b). Given that power is theoretically involved in all movement it is clear that the specific neuromuscular qualities influencing a given sporting action are likely to vary based on the movement characteristics as well as load involved. Despite the numerous neuromuscular factors known to contribute to power production, studies examining changes in power output in rugby players have often just examined the performance of one power based task (Baker and Newton, 2006). In keeping with previous work power is discussed here as a single component. It is however likely to be of far more use to those designing rugby specific strength and power programmes to discuss the specific neuromuscular qualities that contribute to the effective performance of power tasks.

#### 2.2.2.1 Pre-season

Based on current literature it is unclear whether improvements in power can be made over the course of the pre-season period in rugby players (Appendix 5, Table 6.1). O'Connor and Crowe (2007) reported statistically significant increases in lower body peak power of approximately 3% in elite rugby league players whereas Argus *et al.*, 2010 reported reductions in both lower body (-5.2%) and upper body (-5.6%) power output in elite rugby union players. The discrepancies in the findings of these investigations may be in part due to the methods used to assess power output. O'Connor and Crowe (2007) used a ten second maximal cycle ergometer test to assess lower body peak power output. In contrast both of the studies showing a decrease in power output (Argus *et al.*, 2010, Harris *et al.*, 2008) employed jump testing methodologies. Differences between the jump tests however make even the findings of these studies difficult to compare. Harris *et al.* (2007) used a concentric only loaded machine jump squat to assess lower-body power output, whilst Argus *et al.* (2010) used weighted countermovement jump (CMJ) and squat jump (SQJ) protocols. In addition to the difference in SSC utilization in the respective power testing methods, the loading parameters also differed between the two jump testing studies cited. Comparisons between these studies are made more difficult by a lack of available information concerning power training protocols employed during the respective study periods. Without comparable information regarding training objectives, periodisation strategies, exercises employed and volumes of non-resistance training carried out it is difficult for the practitioner to interpret the results.

When examining the findings of studies reporting decreases in power measures it is very difficult to discern if the reported reductions are due to a decrease in a particular characteristic perhaps as a result of detraining or if the observed reduction is a temporary decrease in performance due to fatigue. It is possible that the findings regarding reductions in power performance are due to neuromuscular fatigue and represent a temporary decrease in power output. Neuromuscular fatigue has previously been defined as a reduction in maximal force generation capacity (Cormack, Newton and McGuigan, 2008b). Without measurement of specific neuromuscular qualities such as SSC performance, likely to reflect fatigue states where neural drive is compromised it is difficult for the practitioner to understand why changes in performance of certain qualities may have occurred (Fowles, 2006). Due to the lack of research within rugby union examining the change in different neuromuscular qualities likely to contribute to power output it is unclear whether reported change in power over the pre-season period are due to fatigue or other factors.

#### 2.2.2.2 Competitive season

There is limited data examining changes in power output during the competitive season in the contact codes of football (Appendix 5, Table 2.2). In season-long studies in rugby league players it appears possible for lower body power output to be maintained. Baker (2001) reported no change in lower body or upper body peak power output over the course of a 29-week competitive season in senior professional rugby league players and a 19 week season in college aged players.

Gabbett (2005b) also reported junior amateur rugby league players were able to maintain pre-season improvements in vertical jump power over a 26 week competitive season (-0.7%). In contrast a very similar study by Gabbett (2005a) reported a 5% decline in vertical jump power output in amateur senior rugby league players during the competitive season. It is possible that the decline in lower body power output observed in the senior, amateur players in this study compared to the maintenance reported in the study involving junior players (Gabbett, 2005b) was due to an increase in match intensity, injury rate and a reduction in training volume over the course of the season in the senior group compared to a reduction in these criteria in the junior group (Gabbett, 2005a). Since no studies have examined changes in physiological characteristics compared to match or training load over a season in professional rugby players in either code it is unclear if an increase in game intensity and a reduction in training volume can explain some of the reported decreases in power presented above. Without knowledge of the likely effects of a high frequency of match play on neuromuscular performance it is difficult for practitioners to prepare optimal in-season strategies to maintain or develop power based qualities.

In professional rugby union players, Argus *et al.* (2009) reported maintenance in upper body peak power and a 3% decrease in lower body peak power over a 13 week competition phase. In contrast to this, in a brief training study within a competitive season Argus *et al.* (2012) reported improvements of 12% in lower body power following a combined strength-power training programme. The results of this study must however be interpreted with caution as the study was very short (4 weeks) and at the very beginning of a competitive phase, meaning it is unlikely to show the effects of residual fatigue associated with a long competitive season (Fowles, 2006).

Given the short duration and explosive nature of many important muscular actions within rugby union such as ground contact time in sprinting or accelerating it is likely that RFD has a high level of functional significance (Kraska *et al.*, 2009). RFD can be defined as the rate at which muscular force rises at the onset of muscular contraction (Aargard *et al.*, 2002). Strong relationships have previously been reported between isometric RFD, jumping and Olympic lifting performance

(Haff *et al.*, 1997). It appears that RFD is largely determined by factors such as motor unit synchronisation and firing frequency (Cormie, McGuigan and Newton, 2011a). Given the likely neural nature of this quality it is possible RFD is sensitive to levels of fatigue likely to be observed over a rugby season (Fowles, 2006). However, despite the probable significance of improvements in RFD to performance within rugby union no study has reported changes in this parameter over the course of a season.

Effective SSC performance is also essential to many rugby union movements such as accelerating and changing direction. The SSC is a muscle action in which a muscle is stretched immediately prior to be being contracted. It has been described as the natural form of muscle action and it consists of an eccentric-concentric coupling which leads to a greater force output than seen in a concentric only action (Komi, 1992). Schmidtbleicher (1992) has suggested SSC actions should be classified as either fast or slow based on contraction times. Slow SSC actions are classed as those lasting longer than 250ms (Flanagan and Comyns, 2008). The CMJ would be considered a slow SSC action and the performance of such actions is likely to be related to rugby activities such as early stage acceleration and lineout jumping. Fast SSC actions are generally classed as those lasting less than 250ms, the drop jump (DJ) is considered a fast SSC action and its performance is related to rugby activities such as high speed running (Flanagan and Comyns, 2008).

Various tests of weighted and un-weighted jump performance have been frequently used to assess the change in lower body power production over a season within the contact codes of football (Appendix 5, Table 6.2). However discrepancies in results, the lack of information regarding the nature of the vertical jump protocols employed (Schneider *et al.*, 1998) as well as the use of some concentric only jump tests (Harris *et al.*, 2008) means it is unclear how SSC performance changes over a pre-season or competitive season in elite rugby players. It should also be noted that only one study has examined changes in depth jumps (DJ) and therefore fast SSC performance during a competitive season (Argus *et al.*, 2012). Furthermore, no study has attempted to compare non SSC and SSC actions such as the CMJ and SQJ in order to discriminate the effect of the SSC (McGuigan *et al.*, 2006). This is perhaps surprising considering the importance of the SSC to sports performance and the interest in actions featuring an SSC as a means of quantifying low-level neuromuscular fatigue (Fowles, 2006).

It has been suggested that effective power training programmes must involve consideration of factors which contribute to power production (Cormie, McGuigan and Newton, 2011b). Despite this the way in which such contributory factors change across a season in rugby union players is currently unclear. An understanding of the way in which specific neuromuscular factors which contribute to maximal force production change over the course of a season may therefore help practitioners to optimise training prescription designed to improve or maintain power output.

### 2.2.3 Body Composition Changes

Increasing lean mass is an important conditioning goal within rugby union as it offers the potential to enhance physiological attributes required for success such as strength, power and acceleration (Ahtianen *et al.*, 2005). In contrast increases in fat mass are likely to be detrimental to performance due to subsequent decreases in acceleration and increases in energy expenditure. Although body composition can be analysed in a variety of ways sum of skinfold scores have typically been used in studies examining body composition in rugby players to calculate FFM. (Duthie *et al.*, 2006). FFM can be thought of as the total mass of an individual minus their fat mass

#### 2.2.3.1 Pre-season

Several studies have examined changes in sum of skinfold scores in rugby union players during the pre-season period (Appendix 5, Table 2.1). Holmyard and Hazeldine, (1992) reported international rugby union players significantly improved skinfold scores and therefore body composition over the course of pre-season. Whilst this study was performed prior to rugby union becoming a professional sport in 1995 and significant changes in training demands and player characteristics have happened since this time (Quarrie and Hopkins, 2007) the results are in keeping with most other work examining change in body composition during this phase of the season (Gabbett, 2005a, Rogerson *et al.*, 2007). Based on the available literature it seems that rugby players can expect to see reductions of between 6 and 11% in sum of skinfold scores over the course of the preseason phase (table 2.1).

#### 2.2.3.2 Competitive season

Very few studies have examined changes in body composition during a competitive season in the contact codes of football despite the potential performance consequences such changes could have. In college American football Dos Remedios *et al.* (1995) reported reductions in sum of 7 skinfold scores in both linemen and non-linemen following a 10 week competitive season. This is in contrast to findings in rugby league where both maintenance and increases in sum of skinfold scores of 10% have been reported over a 22 week competitive season (Gabbett 2005a; 2005b). The rugby league players in these studies were amateurs and it is possible these changes do not reflect the way in which sum of skinfold scores are likely to change during a competitive season in professional players. Sum of skinfold scores have been shown to decrease by approximately 4% across a two year period in professional rugby union players (Appleby, Newton and Cormie, 2012) and by approximately 12% across an entire season in academy rugby league players (Till *et al.*, 2014). The failure of these studies to examine changes over different phases of the season however limits their usefulness. To the best of this author's knowledge no study has reported changes in sum of skinfold scores throughout a competitive season in professional rugby league or union players. This represents a limitation of the available research especially when the way in which positive changes in lean mass are likely to influence force output is considered (Crewther *et al.*, 2009b).

## 2.3 Positional variation in changes in physiological characteristics

Despite widely acknowledged differences in force production characteristics and anthropometry (Duthie *et al.*, 2006, Smart *et al.*, 2014) no study has compared changes in physiological characteristics across a season in rugby union based on positional groups. None of the studies examined previously report any difference in strength or power change between backs and forwards across a pre-season or a competitive season (Argus *et al.*, 2009, Argus *et al.*, 2010, Argus *et al.*, 2012). It is however possible such a difference exists. Differences in the change in maximal strength and power between linemen and non-linemen have been reported in college American football (Dos Remedios *et al.*, 1995). Furthermore, despite reporting no data showing differences in changes in maximal strength across a competitive season, Argus *et al.* (2012) suggest it is possible that forwards training may better support maintenance or improvement in maximal strength during a competitive season than that performed by backs. In studies reporting typical in-season weekly training breakdowns in appears likely that backs and forwards are exposed to similar quantities and frequencies of resistance training (Argus *et al.*, 2009, McMaster, McGuigan and Gill, 2015). However, forwards training is likely to involve greater exposure to slow or even isometric, high force activities through scrummaging and mauling. Given that frequency and volume of strength training are known to be important variables in the development of maximal strength (Peterson, Rhea and Alvar, 2005) it is possible that forwards are exposed to a greater total strength stimulus within typical competition phase training compared to backs. At present no data has been reported to support this suggestion. The lack of comparative information regarding physiological change across a season, despite known differences in positional movement demands (Duthie, Pyne and Hooper, 2003, Roberts *et al.*, 2009) represents a further limitation of the available literature.

## 2.4 Factors affecting change in physiological characteristics across a season

It is beyond the scope of this review to examine all factors which may influence change in the physiological characteristics previously discussed. It is however important to highlight some of the factors which may affect the results reported in the work examined in this review.

On an individual player level, total match time across a season is likely to affect the extent and direction of change in that players physiological characteristics. Match play in rugby is known to be associated with reduced power output for several days post match (Mclean *et al.*, 2010). This is in part due to a high frequency of collisions (Duthie, Pyne and Hooper, 2003). Given reduced power output (Mclean *et al.*, 2010) and high levels of muscle soreness (Takarada, 2003) post match, and a high frequency of injury during matches it is likely that players who play frequently across a long competitive season will often be in a sub-optimal state for the training of strength and power. It is also important to consider that players often compete on a weekly basis and therefore can only afford to carry out high-load volume training in the middle of each short micro-cycle before tapering training load to avoid residual fatigue leading into a match (Sykes, 2015). Despite the suggestion that high levels of match time is likely to be detrimental to positive change in physiological characteristics very few studies investigating physiological changes have quantified match exposure over a competitive season. The number of competitive games for the team the subject group is drawn from and match load as a group mean for RPE multiplied by match time has been reported (Gabbett 2005a; 2005b). However at the elite level, rugby union is a sport where match day teams are selected from a squad of players meaning that there is likely to be considerable variation in minutes played within a squad. This means information presenting total games or the loading a squad has been exposed to may fail to accurately reflect the match demands of the subjects within a study. To date no study has looked at the relationship between subject game time and individual change in physiological characteristics across a competitive season.

Both chronological and training age of subjects is also likely to have a significant effect on the extent to which adaptation in strength, power and other characteristics can take place (Baker, 2002). Younger subjects with low training ages will often respond in a more favourable way to a training programme than older more training experienced participants. This is likely due to the known neuromuscular improvements that take place in the early stages of resistance training (Behm, 1995) and perhaps the natural maturation of a young athlete (Argus, 2012). This greater scope for adaptation is also likely to mean that younger, less experienced participants can make improvements across a competitive season even when the resistance training stimulus is less than that of pre-season (Baker and Newton, 2008, Peterson, Rhea and Alvar, 2005). In contrast a more experienced, stronger athlete may require more training stimulus (Baker, 2013). Whilst some of the studies examined above have purposely used younger athletes, it is possible that differences between studies in training ages or chronological ages of subjects may go some way to explaining some of the differences in findings reported.

Given the way in which most studies examine changes within one particular team, a further factor which is likely to have a significant effect on the extent to which physiological characteristics change over the course of the season is the training system adopted by that particular team. In a comparison of strength-power and speed-power programme designs Argus *et al.*, 2012 reported an approximately 8% difference in change in weighted CMJ performance in professional rugby union players after 4 weeks of training. It is widely accepted that exercise selection, periodization, loading strategies and the integration of resistance training into an overall training programme are important factors in the development of strength and power (Cormie, McGuigan and Newton, 2011b). Whilst very few studies provide detailed information regarding the exact nature of the resistance training performed it is likely that differences in training programme content and objectives go some way to explaining some of the differences reported here.

**2.5 Summary**

The available literature shows that levels of strength and power are related to success in rugby football (Baker, 2002, Smart *et al.*, 2014). At present however limited information exists regarding the changes in strength, power and body composition that occur during the pre-season and competitive season in elite rugby union players. Based on work in rugby union and other contact codes of football it would appear that increases in upper and lower body maximal strength will occur during pre-season (Argus *et al.*, 2010, O'Connor and Crowe, 2007). Evidence also suggests maximal lower and upper body strength can be maintained or improved over the competitive season (Argus *et al.*, 2012, Baker, 1998, Baker, 2001, Hoffman and Kang, 2003). It is however unclear how maximal power will change over the course of a pre-season and competitive season as both increases (Gabbett, 2005b), decreases (Argus *et al.*, 2010) and maintenance (Gabbett 2005a) have been reported. Furthermore it is unclear how neuromuscular characteristics such as RFD, SSC and maximal force production likely to underpin the capacity to produce maximal power (Cormie, McGuigan and Newton, 2011b) change over the course of a whole season in professional rugby union.

Increased competitive match exposure has been identified as likely to lead to higher levels of cumulative fatigue and increased chance of performance decreases (Mclean *et al.*, 2010, Hyrosamilis, 2010). No study has however identified the effect of game time exposure on the change in physiological characteristics in professional rugby union players.

Furthermore despite known differences in match movement demands based on playing position very little research attention has been given to potential differences in physiological changes based on positional grouping of players. Without knowledge of the way in which strength, power and body composition are likely to change and the factors related to such changes it is very difficult for practitioners to develop optimal prescriptions for the maintenance and development of key physical attributes within rugby union.

# *Chapter 3:*

# *Methods*

### 3.1 Methods

### 3.2 Subjects

Nineteen male professional rugby union players volunteered to take part in this study (mean ± SD: height 185.3 ± 7.0 cm; body mass 105.1 ± 14.8 kg; age 26.0 ± 5.1 years). The cohort consisted of 5 backs and 14 forwards. All subjects were from a Rugby Football Union (RFU) Championship division team and had been professional for at least one year prior to the start of the study. Each subject was informed of experimental risks and provided written informed consent. A Physical Activity Readiness Questionnaire (PAR-Q) and a blood analysis screening form (see Appendix 1) were completed prior to testing. The study received ethical approval from the Institute of Sport and Physical Activity Research Ethics panel at the University of Bedfordshire. All subjects had at least 2.5 years resistance training experience and were familiar with both jump training and movements similar to an IMTP. Subjects were asked to adhere to their normal diet and only consume water in the 60 minutes prior to data collection. All data collection was carried out following a period of relative rest. This consisted of at least 48 hours prior to data collection where no training or matches were scheduled.

### 3.3 Experimental approach to the problem

In order to examine the change in physiological characteristics over the course of the season, subjects participated in four laboratory based data collection sessions. In each data collection session anthropometric and body composition data were obtained followed by jump and IMTP testing. Each subjects match minutes were recorded based on the official RFU match record cards signed off after each fixture. Changes in characteristics were then examined and the relationships between these and game minutes played were explored.

The four data collection sessions were scheduled over the course of a 41 week season, consisting of an eight week pre-season phase and a 33 week competitive season within which the squad played 28 competitive games (Figure 3.1). The first data collection session was on the first day of pre-season training, prior to any other training taking place and following an off-season break from squad training. The second data collection session was at the end of the pre-season phase (eight weeks later) prior to the first league game. The third was at approximately the middle of the season. There was a period of 17 weeks between the second and third data collection sessions during which time the squad played 14 competitive matches. The third and fourth (final) data collections were separated by 14 weeks within which the squad played 12 competitive matches. The final data collection session was two weeks prior to the end of the competitive season. It had been scheduled to be later in the season however the team did not qualify for any additional play off matches. It was not possible to perform data collection following the final game of the season due to team commitments. The team finished the league season in 9th place out of 12 teams, winning 7 games and losing 16. The team played 6 cup games in a pool format winning 2 games and losing 4. An overview of the year detailing games and training objectives on a week by week basis is presented in appendix 6 (Table 6.4).

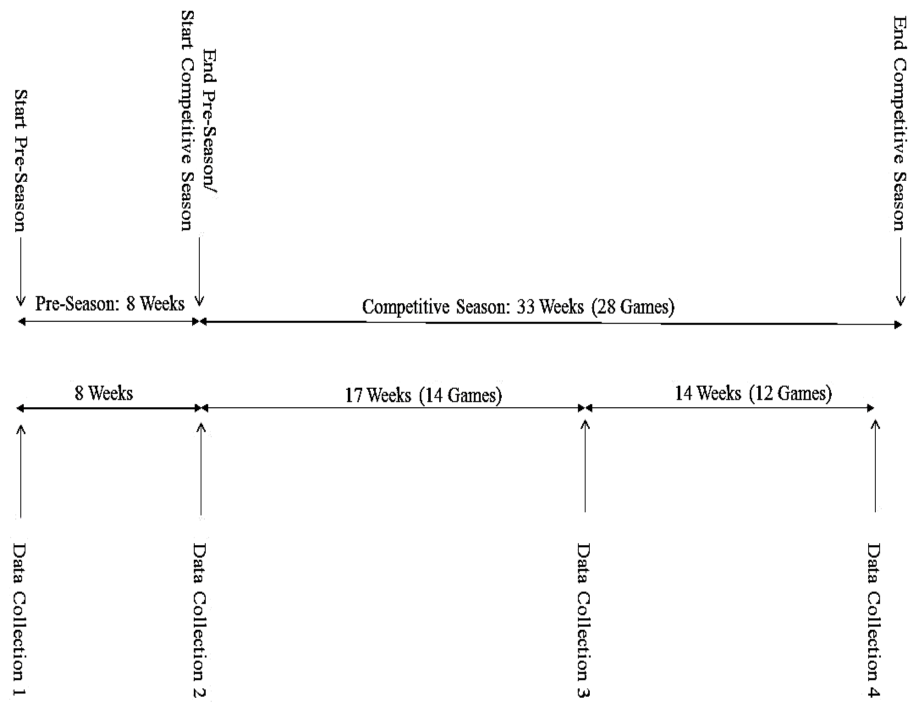


Figure 3.1 Season and data collection timelines for the whole study period.

### 3.4 Training

During the pre-season and competitive season each week typically consisted of resistance training sessions, aerobic/anaerobic conditioning sessions, rugby specific training sessions and one speed session. Throughout the study period subjects followed individualized resistance training programmes addressing their individual performance needs and injury prevention requirements. Resistance training sessions were based around multi-joint movements (Clean, Squat, Deadlift, Leg Press, Lunge variations, Bench Press, Shoulder Press, Chin ups and bench pull) with additional isolated hamstring and shoulder exercises. Strength training sessions in the off-season period were designed to prevent significant detraining and reduce the occurrence of injuries during the pre-season period. The players performed 3 short sessions each week with the focus being placed upon improving mobility, targeting asymmetries and developing trunk strength (Sykes, 2015).

A typical pre-season week is shown in Table 3.1. During the pre-season phase subjects completed four resistance training sessions each week. The resistance training sessions carried out over pre-season were designed to increase maximum strength. Strength training sessions in pre-season typically consisted of 18-25 sets of 1-6 reps at 80-100% 1RM load. Each of these sessions lasted between 55 and 70 minutes. Subjects also typically carried out four aerobic/anaerobic conditioning sessions each week. Three were performed immediately post rugby training and consisted of one or a combination of repeat sprints, conditioning games or wrestling based conditioning drills. These sessions last approximately 20-30 minutes. The fourth was a gym based session consisting of boxing, rowing or cycling intervals. This session lasted approximately 40 minutes. Rugby training sessions lasted approximately 60 minutes and consisted of skill work and team plays. The speed session in both the pre-season and competitive season phase consisted of technical speed and agility drills, resisted sprints and tempo runs. The duration was approximately 30 minutes.

Table 3.1 Outline of a typical week during the pre-season phase in professional rugby union players.

| | Monday | Tuesday | Wednesday | Thursday | Friday |
|---|---|---|---|---|---|
| Session 1 | Speed + Resistance Training | Resistance training | Off | Resistance training | Resistance training + Aerobic/ Anaerobic Conditioning |
| Session 2 | Rugby + Aerobic/ Anaerobic Conditioning | Rugby + Aerobic/ Anaerobic Conditioning | | Rugby + Aerobic/ Anaerobic Conditioning | |

A typical training week during the competitive season is shown in Table 3.2. During the competitive season subjects completed between two and three resistance training sessions per week. (These typically consisted of one strength/power session, one strength session and one power session per week, each session lasting 40-55 minutes). During the competitive season subjects followed alternating blocks of resistance training deigned to improve maximal strength and maximal power qualities respectively (Appendix 6, Table 6.4). Whilst there was some variation in the length of these blocks based on fixtures, generally four weeks of resistance training with maximum strength as the main goal was followed by 3-4 weeks of resistance training designed to enhance power. A down week generally followed the end of a power training cycle. The use of 3-4 week training blocks followed by a week of reduced volume has been recommended for team sport athletes (Gamble, 2006). A total of four complete cycles were performed over the competitive season. During the competitive season Strength sessions typically consisted of 14-20 sets of 1-6 reps at 80-100% 1RM. Power sessions typically consisted of 14-20 sets of 2-6 reps at 50-85% 1RM. One-two aerobic/anaerobic conditioning sessions lasting 10-25 minutes were performed each week within the competitive season consisting of either conditioning games or repeated running efforts. Rugby sessions lasted 40-70 minutes and consisted of position specific skills, general rugby skills and attack and defence organisation. It should be noted that this weekly structure only applied when games were separated by seven days or more. On seven occasions throughout the season games were separated by six days or less and as a result the week was modified to include two resistance sessions and two rugby sessions only.

Table 3.2 Outline of a typical week during the competition phase in professional rugby union players.

| | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday | Sunday |
|---|---|---|---|---|---|---|---|
| Session 1 | Speed + Resistance Training | Resistance training | Off | Resistance training | Off | | Recovery |
| Session 2 | Rugby | Rugby + Aerobic/ Anaerobic Conditioning | | Rugby | | Match | |

### 3.5.1 Procedures

Upon arriving in to the university laboratory subjects' body mass was measured to the nearest 0.1 kg using a digital scale (Seca, Birmingham, United Kingdom). Height was measured using a stadiometer and recorded to the nearest 0.1 cm. Four skinfold sites as described by Durnin and Womersley (1974) were measured by the same tester using the same skinfold calipers (Harpenden skinfold calipers, Baty international, West Sussex, United Kingdom). The skinfold sites (bicep, tricep, subscapular, suprailliac) were located and assessed as described by the International Society for the advancement of Kinanthropometry (Norton *et al.*, 2004). Percent body fat was subsequently calculated from body density based on the work of Siri (1961). Percent body fat and body mass data were used to calculate FFM (FFM = body mass – (body mass x percentage body fat/100) (Slater *et al.*, 2006). A four site skinfold measurement protocol has previously been used by studies investigating anthropometric profiles of elite and international rugby players (Elloumi, Makni and Moalla, 2012, Holmyard and Hazeldine, 1993, Rienzi, Reilly and Malkin, 1999).

Creatine kinase (CK) activity was measured using a finger prick blood sample obtained using standard collection techniques as described by Hamer (2010). This was immediately analysed for CK using universal Reflotron blood analysis methods

(Reflotron Plus Blood Analyser, Roche, Basel, Switzerland). Whilst given the high frequency of competitive games it is likely that rugby union players are frequently training with some degree of muscular soreness (Takarada, 2003), CK levels were monitored to ensure levels of muscle damage were consistent across data collection sessions. This was done as muscle damage has been shown to reduce muscular strength and negatively affect vertical jumping performance (Bryne and Eston, 2002). Prior to jump and IMTP testing subjects performed a standardized 5 minute cycle ergometer warm up. Subjects then performed two warm up jumps of each jump type prior to the maximum effort jump trials. All jump and IMTP testing was performed on a force plate (Kistler Instrumente AG, Winterthur, Switzerland) measuring force output at a sampling frequency of 1000Hz. This has been reported as an appropriate measurement level for both vertical jumps and IMTP trials (McMaster *et al.*, 2014).

### 3.5.2 Jump assessment

Jump testing began with CMJ followed by the SQJ and the DJ respectively. No order effect has been shown when testing SQJ vs CMJ (Kraska *et al.*, 2009). The DJ was performed third.

In the CMJ subjects were instructed to dip and immediately jump for maximum height as part of a continuous movement with no visible pause between upward and downward phases (Young, Pryor and Wilson, 1995). Subjects were allowed to dip to a self-selected depth in the downward phase (Kraska *et al.*, 2009). Measurement of the CMJ allows an athlete's ability to generate power through use of a slow stretch shortening cycle (SSC) to be monitored (Flanagan and Comyns, 2008). Given the importance of movement characterised by a slow SSC in sport, performance within the CMJ has been widely used to assess functional explosive qualities of the lower body (Young, Cormack and Crichton, 2011). Performance in functional SSC activities such as the CMJ has also been suggested as a means of quantifying low frequency fatigue in athletes (Fowles, 2006). The CMJ therefore has the scope to aid the coach in both tracking athlete progress in improving sport specific power and being a useful tool in the monitoring of fatigue.

Prior to the SQJ subjects assumed a squat position with a 90° knee angle measured with a handheld universal goniometer (Kraska *et al.*, 2009). All joint angles were calculated ensuring the fulcrum of the universal goniometer was placed over the centre of rotation of the joint as described by Brosseau *et al.* (2001). This position was standardized between trails for each subject through the use of an adjustable height bar. This was set at the height where it was in light contact with the underside of each subject's hip/glute area when in the correct pause position for the SQJ. The measurement for this took place during the practice jumps. In addition to ensuring the correct pause position this was used to prevent a small countermovement at the initiation of the upward phase of the SQJ. Subjects remained in this position and were instructed to jump following a "3,2,1,GO" countdown (McGuigan *et al.*, 2006). A 3 s pause in this position has been proposed to remove the involvement of the SSC (Haff *et al.*, 1997). The SQJ was monitored as it represents a means of assessing lower body explosive power without use of the SSC (McGuigan *et al.*, 2006). The DJ involves the athlete dropping from a fixed height and performing an explosive vertical jump immediately on landing (Walsh *et al.*, 2004). Subjects performed the DJ from a height of 0.3 m. This height has been cited in previous studies measuring the same construct and has been deemed a safe height for well-trained athletes when tested in a non-fatigued state (Flanagan, Ebben and Randal, 2008, Taube *et al.*, 2012). Subjects were instructed to aim for both maximum height and minimum contact time. Emphasising both the jump height and the need for short contact time in instructions has been shown to lead to shorter contact times and a movement which is more akin to a faster SSC action when compared to only emphasising jump height (Young, Pryor and Wilson, 1995). Subjects were also instructed to 'Step out' and not to raise or lower their centre of mass when stepping forward off the box prior to the jump. This was done to keep actual dropping height consistent (Kibele, 1999). Subjects were required to land on the balls of their feet without allowing their heels to touch the ground between initial ground contact and take off. Subjects performed two trials for each jump type. The jumps were assessed for similarity and a third jump was conducted if the initial data were not considered reliable. In the case of the CMJ and SQJ the jump with the greatest jump height was selected for analysis. The greatest RSI was used to determine the best jump in the

DJ condition. Approximately 1 minute of rest was given between jumps (Kraska *et al.*, 2009) and subjects were instructed to keep their hands on hips in all jump trials (Hatze, 1998). Jump height for all jumps was calculated from force plate data based on flight time as described by Schmidtbleicher (1992). Jump height was calculated based on the flight time method (Linthorne, 2001) using the following equation (Kibele, 1998, Moir, 2008):

$$h = ½(t/2)^2 g(m)$$

In this equation $h$ is jump height (m), t is the flight time of the jump (s), and g is the acceleration due to gravity (9.81m/s²).

### 3.5.3 Isometric mid-thigh pull assessment

Following the jump trials subjects were given approximately 3 minutes rest before beginning IMTP testing (Kraska *et al.*, 2009). All isometric pulls were performed using a custom modified smith machine (Pullum Power Sports, Luton, United Kingdom) placed over the force plate. This apparatus allows the bar to be securely fixed at any height. The data collection time for each pull was set at 6 s. Isometric force time characteristics were evaluated as they have been found to be significantly related to a variety of dynamic performance measures (Haff *et al.*, 1997, Kawamori *et al.*, 2006). Based on previous research subjects positions were standardized so that knee angle as measured with a universal goniometer was 140° (Nuzzo *et al.*, 2008, Haff *et al.*, 2005). Subjects were attached to the bar using lifting straps in order to minimise the impact of grip strength on scores (Haff *et al.*, 2005, Stone *et al.*, 2004). This is particularly relevant in rugby union where anecdotally players frequently report bruising and pain in the hands and therefore possible variation in grip strength following match play. Once commanded to start, subjects were instructed to pull against the immovable bar as hard and fast as possible (Haff *et al.*, 2005). These instructions have been found to produce optimal results when looking at both maximal force and explosive force development (Bemben, Clasey and Massey, 1990).

Maximum force recorded from the force-time curve for each trial was reported as max force. Force at 0.1 and 0.2 s was also recorded from the force-time graph for each pull. These time intervals were chosen as they are close to those which have been shown to be relevant for force development in sprinting and jumping (Mann, 1994). Forces produced at these time intervals were used to calculate RFD at each time point. A 3 minute rest period was given between maximal isometric pulls (Kraska *et al.*, 2009). Subjects completed two maximal effort pulls. If the testers felt that the pull was not maximal, or there was a greater than 250 N difference in maximum force or a large discrepancy in the shape of the force time curve between the first and second pull a third effort was performed (Kraska *et al.*, 2009). For each subject the trial with the highest peak force was selected for further analysis.

### 3.6 Data Analysis

Data collected for CMJ and SQJ was used to calculate eccentric utilization ratio (EUR) for each subject. This is the ratio of CMJ height to SQJ height (McGuigan *et al.*, 2006). Comparison of the CMJ with its additional pre-stretch, to the SQJ allows information regarding an athlete's ability to use the SSC to be obtained (Komi and Bosco, 1978). The ability to utilise the SSC effectively has been described as a critical factor in many sports (McGuigan *et al.*, 2006) and is therefore of great interest to the sport scientist and strength and conditioning coach alike. Data from DJ trials were used to determine reactive strength index (RSI). This is calculated by dividing jump height with the time in contact with the ground prior to take off (McClymont, 2008). RSI has been commonly used in both the literature and a practical setting as a means of quantifying plyometric performance (Flanangan and Comyns, 2008) and offers a further means of quantifying low frequency fatigue (Fowles, 2006). In this investigation DJ performance was evaluated through RSI scores (Argus et al., 2012). In order to separate changes in force production from changes in body mass and to allow further comparison relative strength scores were calculated. Relative IMTP force scores were calculated by dividing a subject's raw force output (N) by their FFM mass (Kg). Force produced at 0.1 s and 0.2 s were used to calculate RFD by dividing change in the force produced by the change in time (Wilson *et al.*, 1995). It has been suggested that the ability to produce force rapidly may be more important than maximum force production for performance in many sports (Stone *et al.*, 2003).

### 3.7 Statistical Analysis

Statistical analyses was carried out using IBM SPSS version 21 (SPSS Inc, Chicago, IL, USA). Prior to the application of inferential statistical analyses, quantile-quantile (Q-Q) plots and histograms were used to assess the normality of data. Where normal distribution was not found dependent variables were log transformed to reduce bias due to non-uniformity of error. Linear mixed models (LMM) were then applied to examine the relationships between the dependent variable at each of the testing points. Whilst LMM does not rely on the assumption that data is normally distributed it does require residuals to come from a normally distributed population. Given that a substantially skewed data set is likely to have skewed residuals, assessment of normality and transformation was carried out as a pre-emptive measure. Linear mixed models were used as they can accommodate missing data and also apply different covariate structures to repeated measures data. Both fixed and random factors were used for each dependent variable, testing session, positional group and interaction (test x positional group). In each case residual covariance and Akaike's information criterion statistics were used to identify the most appropriate model. The use of LMM also offers the advantage over general linear model statistics of not requiring independence of data and being able to accommodate individual subject variance in intercepts and slopes. Sidak post hoc tests and pairwise comparisons were used to investigate the statistically significant main effects found. Histograms and scatter plots were used to investigate the normality and homogeneity of variance of residuals. In all situations the assumptions of uniformity and normal distribution of residuals were supported.

In order to establish the practical significance of changes in subject characteristics mean effect sizes were calculated. The significance of the effect size was described as Cohen (1988), where 0.2, 0.5 and 0.8 are said to describe small, medium and large effect respectively. Only those of statistically significant variables are reported. The number of participants required to give this study sufficient statistical power to detect minimum worthwhile effect was not determined *a priori*.

Pearson correlation coefficients ($r$) were calculated to examine the relationships between the percentage change in subject characteristics and subject match exposure over the whole and parts of the season. The strength of these relationships was also determined based on the work of Cohen (1988). A small effect was classified as $r = 0.10$-$0.29$, a moderate effect as $r = 0.30$-$0.49$ and a large effect as $r \geq 0.5$. Statistical significance for all analyses was set at $p \leq 0.05$ and all outcome measures were summarized as means ± SD.

Reliability in this study was quantified as typical error expressed as coefficient of variation (CV) (Hopkins, 2000). In each case CV was calculated by dividing the standard deviation of subject change scores by the square root of 2 (1.414) and subsequently dividing the value obtained from this by the overall mean (Hopkins, 2000). A CV was calculated for all jump types, raw IMTP measures and sum of skinfolds. It was found to be ≤11.8% in all cases. A CV of <10% has been deemed to represent good reliability (Atkinson and Nevill, 1998) and 10-15% as acceptable reliability (Brughelli and Van Leemputte, 2013, Stokes, 1985).

# *Chapter 4:*

# *Results*

## 4.1 Results

### 4.1.1 Changes in whole group characteristics across the season

Changes in whole group characteristics throughout the season are shown in Table 4.1

### 4.1.2 Force development characteristics

Raw peak IMTP force (IMTP peak) increased by 11.7% over the whole season (ES = 0.42, small). It increased by 6.9% between July and September and by 2.9% and 1.6% between September and January and January and April respectively. Whole group scores for IMTP peak in July were significantly lower than those for September, January and April ($F = 24.1$, $p < 0.01$). There was no significant difference between scores in September, January and April ($p \geq 0.17$). Statistical significance for all analyses was accepted as $p \leq 0.05$ Relative peak IMTP force (relIMTP peak) increased by 10.7% over the course of the whole season (ES = 0.22, small). Increases in relIMTP peak of 6.4% and 4.3% occurred between July and September and between September and January respectively. It was maintained between January and April (-0.28%) however, relIMTP peak in January and April was significantly higher than that in July ($F = 20.0$, $p < 0.01$). There were no significant differences between scores for September, January and April ($p \geq 0.06$). Raw IMTP force at 0.1 s (IMTP 0.1) increased by 3.2% over the whole season. Maintenance in this parameter was observed between July and September (-0.4%) followed by an increase of 3.7% between September and April. Relative IMTP force at 0.1s (relIMTP 0.1) increased by 1.2% over the whole season. A decrease in relIMT 0.1 of -1.5% occurred between July and September and an increase of 2.7% between September and April. RFD at 0.1 s (RFD 0.1) increased by 5.0% across the whole season with decreases of -10.9% occurring between July and April and increases of 18.0% taking place between September and April. Raw IMTP force at 0.2 s (IMTP 0.2) remained unchanged throughout the whole season (0.6%). Relative IMTP force at 0.2 s (relIMTP 0.2) decreased by -1.5% over the whole season showing small decreases at each subsequent data collection session. RFD at 0.2 s (RFD 0.2) showed increases of 4.4% across the whole season with an increase of 10.9% occurring between July and January and a decrease of -5.8% occurring between January and April. There were no statistically significant differences between raw or relative IMTP scores or RFDs for 0.1 s or 0.2 s over the course of the season for the group as a whole ($p \geq 0.46$).

### 4.1.3 Changes in jump measures and SSC performance

EUR increased by 2.8% over the whole season. A decrease in EUR of -1.8% took place between July and September. This was followed by an increase of 3.7% between September and January and 0.9% between January and April. A statistically significant difference was found between EUR in September and April ($F = 4.4$, $p = 0.04$, ES = 0.25, small). No other differences in EUR reached statistical significance ($p \geq 0.55$). An increase in CMJ height of 2.1% was found across the season as a whole. CMJ height was maintained (-0.4%) between July and September and increased by 2.5% between September and April. In contrast SQJ height remained unchanged (-0.62%) and RSI showed a small decrease (-1.5%) over the whole season. There were no statistically significant differences between CMJ, RSI or SQJ over the course of the season for the group as a whole ($p \geq 0.46$).

### 4.1.4 Body Composition

Fat free mass increased by 2.2% over the whole season. Increases of 1.7% and 0.6% in FFM took place between July and September and September and April respectively. FFM was found to be significantly higher in September, January and April versus July ($F = 13.6$, $p < 0.01$, ES = 0.09, trivial).

Body mass decreased by -1.3% between July and September. This suggests a reduction in fat mass as well as an increase in lean muscle mass during the pre-season period. Body mass increased by 1.7% between September and April. Changes in mass for the whole group however did not reach statistical significance ($p \geq 0.71$).

There was also no significant difference between CK levels between stages of the season or positional groups ($p \geq 0.395$).

Table 4.1 Changes in whole group characteristics throughout the full season.

| | July | September | January | April |
|---|---|---|---|---|
| Mass (kg) | 105.11±14.85 | 103.73 ± 15.62 | 105.94 ±13.55 | 105.53 ± 14.78 |
| FFM (kg) | 83.52±9.33 | 84.90±9.41* | 84.96±8.45* | 85.37±9.17* |
| CK (U/L) | 338±195.43 | 315.88±209.18 | 296.18±305.98 | 366±296.14 |
| CMJ (cm) | 40.42±5.94 | 40.26±5.59 | 40.69±5.76 | 41.30±5.89 |
| RSI | 1.26±0.29 | 1.26±0.24 | 1.21±0.31 | 1.24±0.30 |
| SQJ (cm) | 36.90±5.10 | 36.26±4.73 | 36.72±5.49 | 36.67±5.20 |
| EUR | 1.09±0.05 | 1.07±0.06 | 1.11±0.06 | 1.12±0.06† |
| IMTP 0.1 (N) | 2169.21±497.00 | 2159.47±507.03 | 2191±441±13 | 2239.41±531.24 |
| RFD 0.1 (N/s) | 11891.98±5408.09 | 10595.77±6150.84 | 12620.65±5482.91 | 12486.07±6577.65 |
| IMTP 0.2 (N) | 2982.46±653.40 | 3026.83±681.00 | 3014.33±607.27 | 3002.38±548.06 |
| RFD 0.2 (N/s) | 9405.37±3641.95 | 9978.26±3586.81 | 10433.73±3765.74 | 9826.00±3616.71 |
| IMTP PEAK (N) | 3844.66±661.39 | 4109.61±508.64* | 4227.15±436.76* | 4293.56±546.01* |
| relIMTP 0.1 (N/kg) | 25.97±6.06 | 25.58±5.24 | 25.89±4.98 | 26.28±6.57 |
| relIMTP 0.2 (N/kg) | 35.71±11.26 | 35.65±7.04 | 35.48±7.31 | 35.17±6.92 |
| relIMTP PEAK (N/kg) | 45.56±5.4 | 48.49±3.97 | 50.57±4.42* | 50.43±5.18* |

Note: FFM, fat free mass; CK, creatine kinase; CMJ, countermovement jump; RSI, reactive strength index; SQJ, squat jump; EUR, eccentric utilisation ratio; IMTP 0.1, isometric mid-thigh pull force 0.1 s; IMTP 0.2, Isometric mid-thigh pull force 0.2 s; IMTP PEAK, Isometric mid-thigh pull peak force; relIMTP 0.1, relative isometric mid-thigh pull force 0.1 s; relIMTP 0.2, relative isometric mid-thigh pull force 0.2 s; relIMTP PEAK, peak relative isometric mid-thigh pull force. *denotes statistically significant from initial pre-season testing. † denotes a statistically significant different from the beginning of the competitive season.

### 4.2.1 Changes in subject characteristics across the season by positional group

The way in which each characteristic varied across the season by positional group is shown in Table 4.2 and Figures 4.1 and 4.2. A graphical presentation is given in appendix 7 (figures 5.1 and 5.2). Forwards and backs both showed increases in IMTP peak, relIMTP peak and FFM across the whole season. The largest part of the total increase in these scores came in the pre-season phase (July-September) for both positional groups. Both groups showed a similar pattern for changes in FFM across the season, showing overall improvements during pre-season and maintenance of these changes over the competitive season. In the pre-season phase (July-September) the backs reported decreases in all jump measures (CMJ, SQJ, EUR, RSI) and IMTP 0.1 and relIMTP 0.1. Improvement and maintenance where reported in IMTP 0.2 and relIMTP 0.2 respectively. In the same period forwards also experienced decreases in CMJ, SQJ and EUR but showed maintenance of RSI and improvements in IMTP 0.1 and relIMTP 0.1. Between September and April both positional groups showed improvements or maintenance in CMJ, SQJ, EUR, IMTP 0.2 and both measures of IMTP peak force. There was however variation between the positional groups in terms of the change in RSI and both IMTP 0.1 and relIMTP 0.1 during this period. None of the percentage change scores for either the whole season or any of the time periods between data collection sessions can be considered practically meaningful based on the definition of effect sizes provided by Cohen (1988).

Table 4.2 Percentage change in testing scores across the season for the positional groups.

| | Forwards (n=14) | | | | Backs (n=5) | | | |
|---|---|---|---|---|---|---|---|---|
| | Whole Season | July-September | September-January | January-April | Whole Season | July-September | September-January | January-April |
| MASS (kg) | 1.06±2.34 | 0.30±1.70 | 1.31±2.54 | 0.02±1.52 | 1.13±3.22 | 0.31±1.37 | 2.33±0.94 | -1.50±1.95 |
| FFM (kg) | 1.52±1.83 | 1.57±1.33 | -0.50±2.36 | 0.87±1.17 | 2.02±1.93 | 1.91±1.02 | 0.52±1.84 | -0.39±1.39 |
| CMJ (cm) | -1.08±5.60 | -4.34±3.39 | 2.22±3.51 | 0.73±3.28 | 2.87±2.48 | -3.75±4.01 | 3.62±4.05 | 2.52±3.09 |
| RSI | 1.83±15.55 | -0.02±11.01 | -1.51±15.20 | 5.47±10.33 | -5.06±15.92 | -13.89±7.44 | 8.47±14.21 | -1.02±9.60 |
| SQJ (cm) | -1.04±8.40 | -1.98±3.59 | 1.29±3.12 | 0.44±6.92 | 0.13±2.38 | -1.82±2.68 | 2.71±9.43 | -0.45±6.44 |
| EUR | 0.13±8.16 | -2.86±5.98 | 0.97±3.67 | 0.45±5.58 | 2.78±2.67 | -1.95±3.44 | 1.44±6.41 | 3.29±5.58 |
| RFD 0.1 | 8.40±19.81 | -10.12±37.42 | 22.62±28.06 | -1.64±21.24 | -5.26±21.63 | -13.24±22.31 | 7.86±28.47 | 1.25±20.38 |
| RFD 0.2 | 2.87±19.24 | 7.14±22.08 | 2.33±17.32 | -6.18±21.35 | 8.65±12.73 | 2.67±7.00 | 12.13±23.97 | -5.62±14.89 |
| IMTP PEAK (N) | 8.45±14.22 | 5.09±8.01 | 3.06±5.96 | 1.99±7.09 | 14.87±13.13 | 16.24±7.19 | 6.02±9.03 | -3.94±5.43 |
| relIMTP 0.1 (N/kg) | 5.28±17.53 | 2.02±14.92 | 5.94±14.99 | 0.62±14.77 | -9.43±10.43 | -9.05±11.38 | -4.04±14.13 | 3.64±11.05 |
| relIMTP 0.2 (N/kg) | -1.22±11.95 | -0.41±12.22 | 2.19±13.34 | -1.33±12.53 | -0.89±4.30 | -0.18±8.99 | 0.13±15.50 | 1.40±13.56 |
| relIMTP PEAK (N/kg) | 6.56±12.83 | 3.47±7.77 | 3.59±5.79 | 1.11±6.94 | 12.54±11.84 | 13.61±7.51 | 5.49±9.11 | -3.56±5.23 |

Note: FFM, fat free mass; CMJ, countermovement jump; RSI, reactive strength index; SQJ, squat jump; EUR, eccentric utilisation ratio; IMTP 0.1, isometric mid-thigh pull force 0.1s, IMTP 0.2, isometric mid-thigh pull force 0.2s; IMTP PEAK, isometric mid-thigh pull peak force; relIMTP 0.1, relative isometric mid-thigh pull force 0.1; relIMTP 0.2, relative isometric mid-thigh pull force 0.2; relIMTP PEAK, peak relative isometric mid-thigh pull force. No statistically significant differences were found.

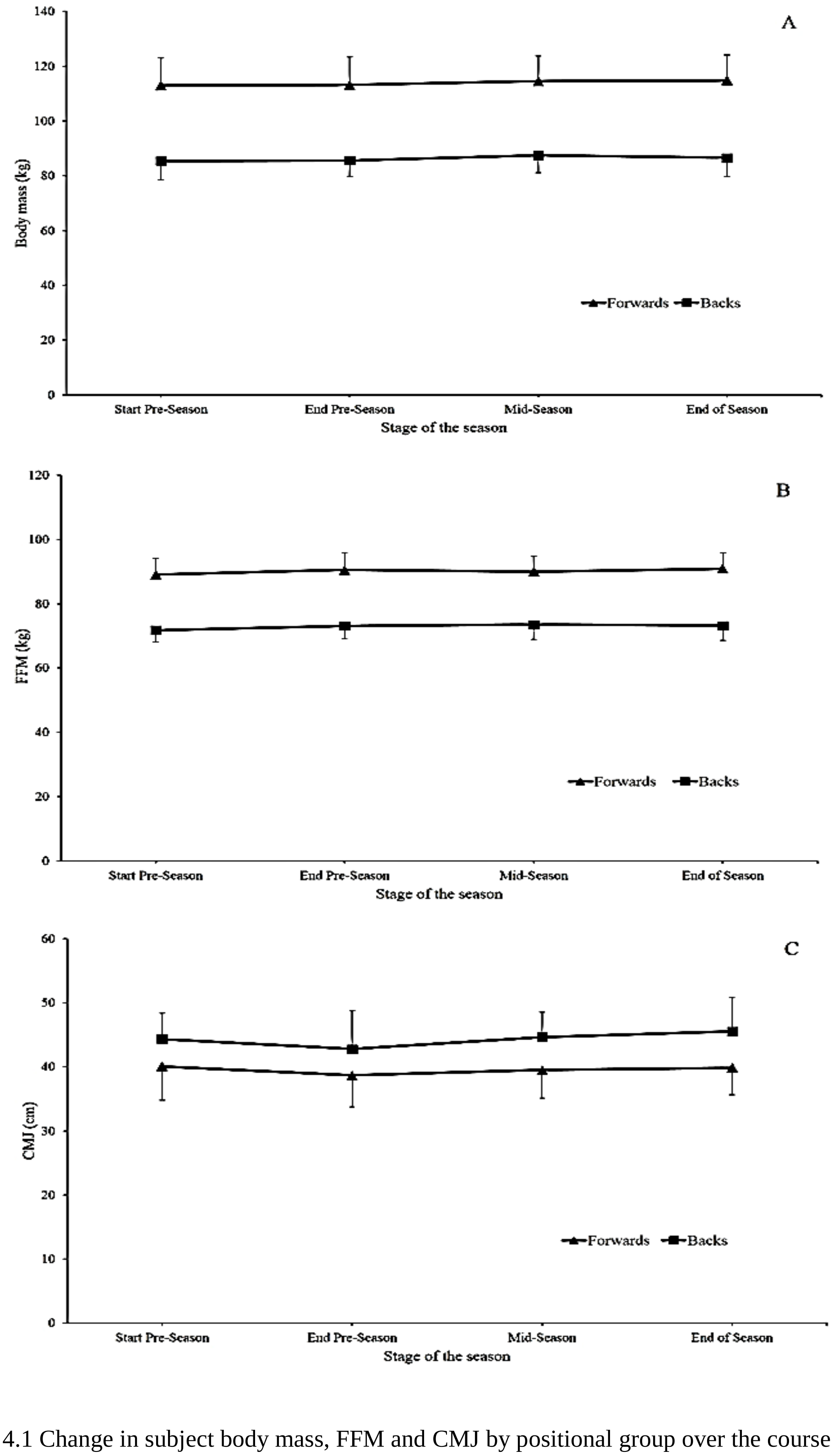


Figure 4.1 Change in subject body mass, FFM and CMJ by positional group over the course of the season. Note; FFM, Fat free mass; CMJ, countermovement jump.

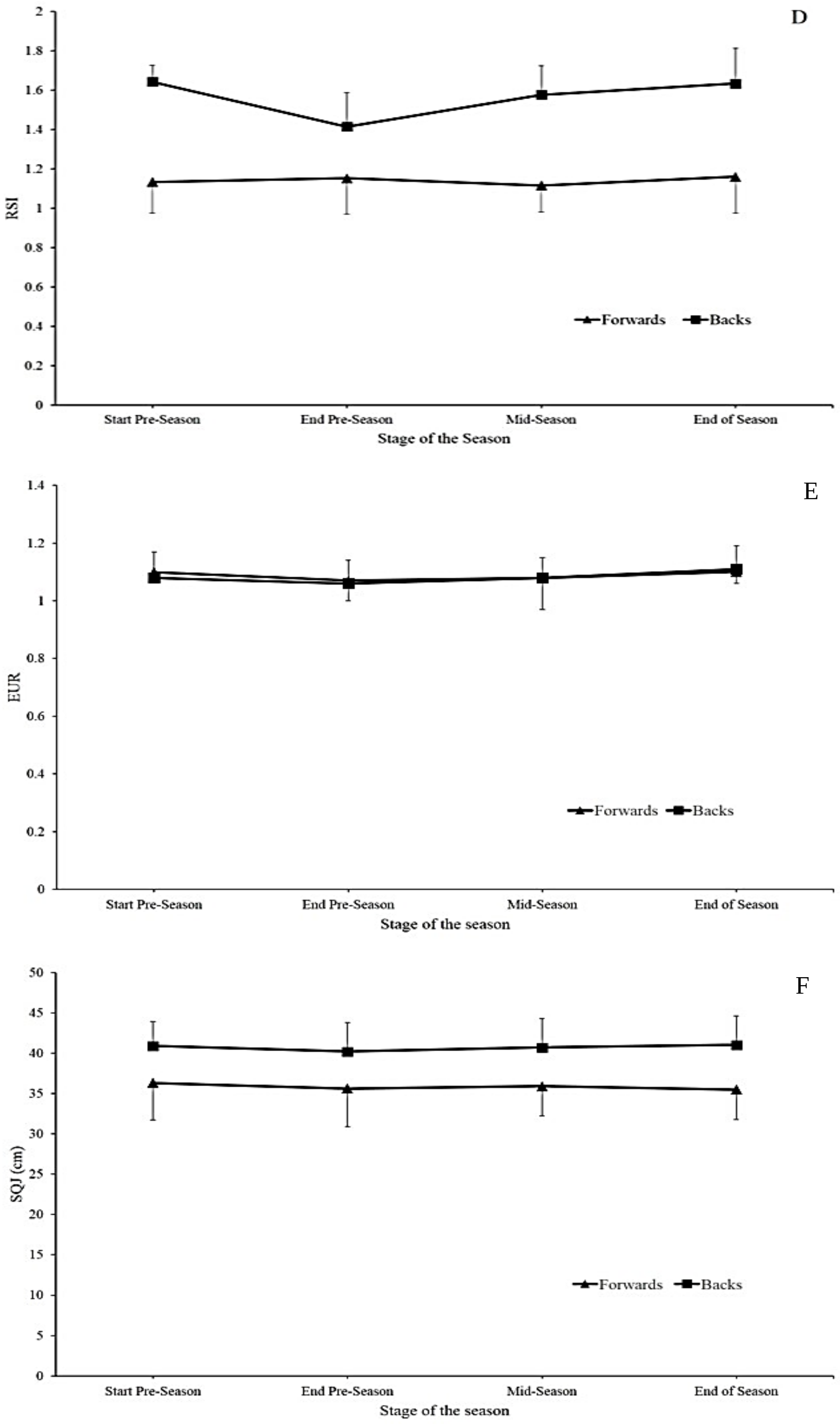


Figure 4.2 Change in subject characteristics by positional group over the course of the season. Note; RSI, reactive strength index; SQJ, squat jump; EUR, eccentric utilisation ratio.

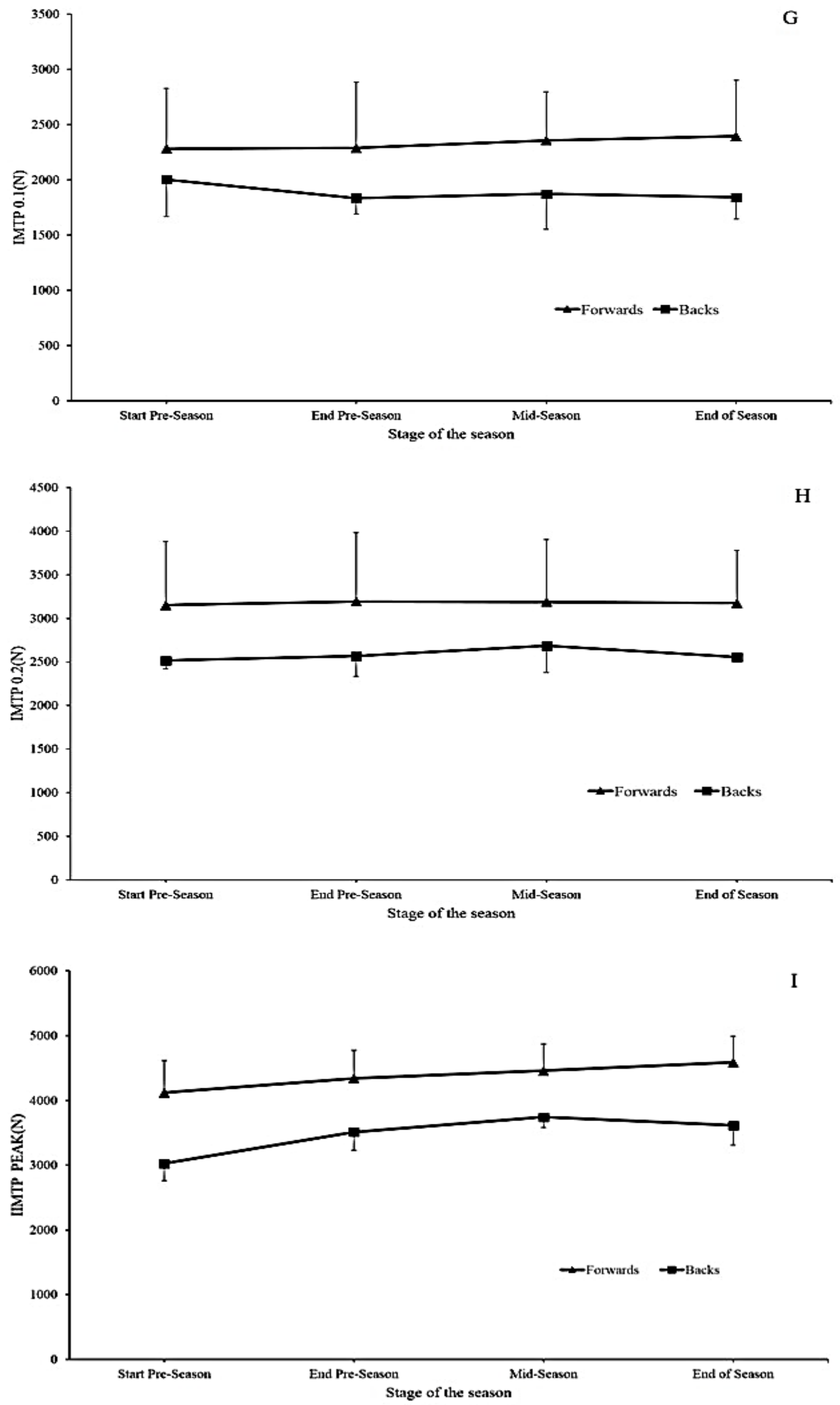


Figure 4.3 Change in subject raw IMTP scores by positional group over the course of the season.
Note; IMTP 0.1, Isometric mid-thigh pull force 0.1s, IMTP 0.2, Isometric mid-thigh pull force 0.2; IMTP PEAK, Isometric mid-thigh pull peak force.

### 4.3.1 Differences between positional group characteristics

Over the whole season forwards were found to have 30.5% and 23.6% higher body mass and FFM respectively compared to backs. Forwards mean raw IMTP peak for the whole season was 26% higher than that of backs. Forwards recorded mean IMTP 0.1 and IMTP 0.2 scores were 30% and 23.2% higher respectively that those of backs. Statistically significant differences were found between the two positional groups for body mass ($F = 44.6$, $p < 0.01$), FFM ($F = 47.0$, $p = < 0.01$) and IMTP peak scores ($F = 19.0$, $p < 0.01$). Differences in groups for IMTP 0.1 and IMT 0.2 were not found to be statistically significant ($p \geq 0.13$). Mean whole season RSI was found to be 37.4% higher in backs than forwards. Backs also showed higher mean whole season scores for SQJ (13.7%) and CMJ (12.1%). Statistically significantly differences were found between positional groups for RSI ($F = 14.5.0$, $p < 0.01$) and SQJ ($F = 5.0$, $p = 0.04$). Difference between the two groups for CMJ however failed to reach statistical significance ($p \geq 0.08$). There was less than a 2% difference between the positional groups for scores for relative maximum force IMTP, relative IMTP scores at 0.1s and 0.2s and EUR. No Statistically significant differences were found between positional groups for relative IMTP scores ($p \geq 0.42$).

### 4.4.1 The effect of match minutes on changes in subject characteristics

Table 4.3 shows the mean match minutes played by the whole group and the two positional groups for the whole season and the periods between testing dates.

Table 4.3 Minutes played by whole and positional groups.

| | Whole season minutes | Minutes played September-January | Minutes played January-April |
|---|---|---|---|
| Whole group | 920 ± 380 | 565±277 | 355±172 |
| Forwards | 820 ± 378 | 508±288 | 312±170 |
| Backs | 1198±203 | 723±158 | 474±112 |

Note: Total minutes only includes league and cup games played during the competitive season.

Pearson correlation coefficients exploring the relationship between change in physiological characteristics and match exposure are presented in Table 4.4. Match minutes for the whole season and the periods of the season between both September and January and January and April were examined. Whole season match minutes were moderately correlated with total percentage change in raw ($r = 0.36$, $p = 0.07$) and relative ($r = 0.37$, $p = 0.06$) IMTP peak force scores. There was a small negative correlation between whole season match minutes and percentage change in RSI ($r = -0.15$, $p = 0.27$), SQJ ($r = -0.16$, $p = 0.26$) and both raw ($r = -0.21$, $p = 0.19$) and relative ($r = -0.23$, 0.18) IMPT 0.1s force scores. None of the correlations between whole season match minutes and change in physiological variables reached statistical significance.

Match minutes played in the first part of the season (September to January) were found to be moderately, positively correlated with total percentage change in IMTP peak ($r = 0.35$, $p = 0.07$) and relIMTP peak ($r = 0.36$, $p = 0.07$). Small negative correlations were found between minutes played in the first half of the season and total percentage change in CMJ ($r = -0.13$, $p = 0.29$) and RSI ($r = -0.18$, $p = 0.23$). In contrast, match minutes played in the second part of the season (January to April) were also found to moderately correlated with whole season percentage change in CMJ ($r = 0.42$). This relationship was found to be statistically significant ($p = 0.04$). Moderate negative correlations coefficients were found to exist between minutes played in the second part of the season and both IMTP 0.1 ($r = -0.30$, $p = 0.11$) and relIMTP 0.1 ($r = -0.30$, $p = 0.11$) IMTP 0.1. Small, positive correlations were found between match minutes played in the second part of the season and total percentage change in IMTP peak ($r = 0.23$, $p = 0.17$), relIMTP peak ($r = 0.24$, $p = 0.16$), RFD at 0.1 s ($r = 0.28$, $p = 0.17$) and EUR ($r = 0.27$, $p = 0.14$). There was a small negative correlation between match minutes played in this phase and whole season change in SQJ ($r = -0.25$, $p = 0.15$).

Moderate, negative correlations were also found to exist between minutes played between September and January and change within this period in IMTP 0.2 ($r = -0.32$, $p = 0.12$), relIMTP 0.2 ($r = -0.32$, $p = 0.12$) and percentage change in FFM ($r = -0.38$, $p = 0.06$). In contrast a moderate, positive correlation was found between change in RFD at 0.2 s and minutes played between September and January (r =

0.31, p =0.11). Small negative correlations were found between minutes played between January and April and percentage change in the same time period in mass (r = -0.23 p =0.21), IMTP peak (r = -0.23, p =0.19) and relIMTP peak (r = -0.17, p =0.26). It should be noted that none of the correlations reported reached statistical significance.

Table 4.4 Correlations between percentage change in physical characteristics and exposure to match minutes for the whole group.

| | Total % Change-whole Season minutes | Total % change- minutes September-January | Total % Change- minutes January-April | September-January % change- minutes September-January | January-April % change- minutes September-January | January-April % change- minutes January to April |
|---|---|---|---|---|---|---|
| MASS | 0.085 | 0.045 | 0.115 | -0.035 | -0.131 | -0.233 |
| FFM | 0.093 | 0.077 | 0.080 | 0.073 | -0.107 | -0.379 |
| CMJ | 0.093 | -0.133 | 0.418* | -0.098 | -0.074 | 0.186 |
| RSI | -0.151 | -0.182 | -0.041 | 0.019 | -0.114 | 0.062 |
| SQJ | -0.159 | -0.063 | -0.249 | 0.079 | -0.306 | 0.121 |
| EUR | 0.185 | 0.087 | 0.267 | 0.023 | 0.313 | 0.025 |
| IMTP raw 0.1 | -0.210 | -0.101 | -0.301 | -0.027 | -0.138 | -0.122 |
| RFD 0.1 | 0.115 | -0.045 | 0.278 | 0.305 | 0.470 | 0.460 |
| IMTP raw 0.2 | 0.098 | 0.078 | 0.091 | -0.322 | 0.123 | 0.093 |
| RFD 0.1 | 0.181 | 0.140 | 0.183 | -0.203 | 0.010 | -0.132 |
| IMTP raw max | 0.355 | 0.345 | 0.228 | -0.096 | 0.036 | -0.225 |
| IMTP rel max | 0.372 | 0.36 | 0.241 | -0.133 | 0.055 | -0.165 |

Note: FFM, Fat free mass; CMJ, countermovement jump; RSI, reactive strength index; SQJ, Squat jump; EUR, eccentric utilisation ratio; RFD 0.1, rate of force development 0.1 s; RFD 0.2 s, rate of force development 0.2 s; IMTP 0.1, Isometric mid-thigh pull force 0.1 s, IMTP 0.2, Isometric mid-thigh pull force 0.2 s; IMTP MAX, Isometric mid-thigh pull peak force, relIMTP 0.1, relative isometric mid-thigh pull force 0.1 s, relIMTP 0.2 relative isometric mid-thigh pull force 0.2 s ; relIMTP MAX peak relative isometric mid-thigh pull force. * denotes statistical significance.

# *Chapter 5:*

# *Discussion*

## 5.1 Discussion

The primary aim of this investigation was to examine changes in physiological characteristics over the course of a whole season in elite rugby union players. Findings from this investigation show it is possible to improve maximal strength over a whole season. In contrast power based measures will likely show decreases during the pre-season period and small improvements or maintenance over the competitive season. This investigation also shows it is possible to increase FFM during the pre-season period and maintain this level throughout the competitive season.

Secondly this investigation sought to examine the effect of players' positional group on the change in physiological characteristics over the whole season. The results presented here show the two playing groups follow a similar pattern of change over the whole season although backs reported much larger decreases in RSI and IMTP force at 0.1 s during the pre-season period. The final aim of this investigation was to examine the effects of match exposure on change in physiological characteristics. The results of this investigation suggest high match minutes do not impair the development of strength but may impact negatively on the development of some power based characteristics.

### 5.2.1 Changes in physiological characteristics over the course of the season

### 5.2.2 Peak force output

Whilst most studies measuring physiological change within the contact codes of football have examined what they termed maximal strength the present investigation examined peak force output using an IMTP measure. The term strength is used interchangeably with IMTP peak force output for ease of comparison with studies measuring strength through the performance of resistance training exercises requiring high load, low velocity force production (Cormie *et al.*, 2008). Isometric testing has previously be found to be highly related to dynamic performance (Haff *et al.*, 2005, Stone *et al.*, 2004).

In this investigation increases in both IMTP peak and relIMTP peak were observed over the pre-season and competitive season. Whilst peak force output was significantly higher at the end of the season compared to the beginning of pre-season it is clear the largest increase in peak force output was observed during the pre-season period. Increases in 11.7% in IMTP peak were observed from the start of pre-season to end of the season. In the 8 week pre-season period (July to September) IMTP peak increased by 6.9% whereas the increase over the whole 33 week competitive season (September to April) was 4.5%. A very similar pattern was observed for relIMTP peak. It has been shown that frequency and volume are key variables in bringing about positive adaptations within maximal strength (Peterson, Rhea and Alvar, 2005). It is therefore likely that the greater increases in peak force output in the pre-season phase compared to the competitive season were due to the greater frequency and higher total volume of resistance training performed within this phase. It is possible that the greater increase in peak force output observed during the preseason period was in part due to the increase in FFM that occurred during the pre-season compared to the maintenance of FFM during the competitive season. Previous work has shown that a strong relationship exists between increases in muscle cross sectional area and increases in maximal strength (Cribb, Williams and Hayes, 2006, Blazevich, Gill and Shi, 2006). It has been suggested this is as a result of increases in the percentage of type II fibres within a muscle and/or changes in angle of pennation (Blazevich, Gill and Shi, 2006, Blazevich *et al.*, 2007). Whilst this investigation does not provide any indication as to the specific changes in morphology that may be taking place as part of an increase in FFM, it does suggest an increase in FFM appears to contribute to an increase in maximal strength. Previous work looking at strength changes in rugby union players over a multi-season period has shown increases in lean mass are highly related to improvements in maximal strength (Appleby, Newton and Cormie, 2012). Practitioners should therefore consider including hypertrophy training in a periodized plan designed to bring about increases in maximal strength.

An additional reason for the greater increase in strength during the pre-season phase versus the competitive season is that the pre-season phase follows the off-season during which time a decline in some physical qualities often takes place (Nirmalendran and Ingle, 2010). Whilst subjects were given off-season training plans, the reduced volume, loading and unsupervised nature of training within this period means detraining is likely. Detraining in maximal strength has been previously reported in elite athletes during the off-season (Argus, 2012, Hakkinen and Komi, 1985). It is therefore possible that the increases in strength during the pre-season are largely a return to previous levels.

The finding of increases in strength following the pre-season phase is very much in keeping with the existing literature. Increases in maximal strength following the pre-season phase have been previously reported in both rugby league and rugby union (Harris *et al.*, 1998, Argus *et al.*, 2010). An increase in maximal strength of 11.3% was reported in professional rugby union players based in New Zealand (Argus *et al.*, 2010). This is larger than the 6.9% improvement reported here. It is possible this difference could be due to the greater frequency of resistance training within the typical pre-season week for the New Zealand based players. Five resistance training sessions were performed each week by the New Zealand based players compared to four each week in the present study. Hoffman *et al.* (1990) have suggested that a weekly dosage of five sessions is likely to bring about greater performance improvements than three or four sessions. The difference between the magnitude of improvement in the two studies is also likely due to the different strength testing measures employed. It is possible that the more complex movement of the box squat 1RM test used by Argus *et al.* (2010) has more scope for technical improvement over a short period of time than the fixed position IMTP test employed in the present study. It is also possible that improvements in lifts such as the box squat can occur through improving force output around specific 'sticking points' (approximately 32°) within the motor pattern (Hales, Johnson and Johnson, 2009). The relevance of improvements in force output at such joint angles to rugby union performance is unclear. In contrast improvements in IMTP peak force occur at a specific knee angle (120-140°) known to have high relevance to sporting movements (Haff *et al.*, 2005). It should also be considered that the box squat exercise used by Argus and colleagues (2010) was prescribed within training programmes as well as testing. This is likely to lead to greater familiarisation than would have been experienced with the IMTP in the present study given it was used exclusively as a testing modality. In addition to this it should be noted that Argus and colleagues (2010) did not publish reliability statistics for the subjects within their study.

The 4.5% improvement in strength reported in this study over the course of the competitive season is in keeping with much of the available literature. Previous studies in rugby league (3%), rugby union (4.8%) and American football (4%) have shown small increases or maintenance of lower body maximal strength over a competitive season (Argus *et al.*, 2012, Baker, 2001, Fry and Kramer, 1987, Schneider *et al.*, 1998). Several studies have in contrast reported decreases in lower and upper body maximal strength over the course of a competitive season in the contact codes of football (Dos Remedios *et al.*, 1995, Legg and Burnham, 1999). The differences between testing methodologies employed by the studies will explain some of the variation in strength change reported. Variation between studies in terms of the volume and frequency of both resistance training and other types of training is however likely to be the key variable in determining the direction and magnitude of strength change (Peterson, Rhea and Alvar, 2006). Alongside the work of Argus *et al.* (2010) the findings reported here suggest it is possible for players to improve lower body maximal strength over the competitive season providing between 2 and 3 resistance training sessions are performed each week. This study builds on the work of Argus *et al.* (2010) as it shows it is possible for this strength increase to take place for a much longer period of time than the 13 weeks these authors examined. The present study also adds to that of Argus *et al.* (2010) by providing reliability for strength measures employed.

Whilst the IMTP test has not been previously used to evaluate changes in strength across a whole season it has been used to examine the strength characteristics of a variety of elite athletes including rugby league players (Stone *et al.*, 2004, West *et al.*, 2011). The maximal strength values reported for subjects in this study are approximately 20% higher than those reported for professional rugby league players by West and colleagues (2011). This suggests the subjects used here are of at least a similar training status.

### 5.2.3 Rate of force development

Within this investigation IMTP trials were also used to determine RFD. Whole group reductions of approximately 11% in RFD 0.1 occurred following the pre-season phase. When examining such reductions in any of the measures reported here it is difficult to discern if the observed decreases are due to a decline in a particular characteristic, perhaps as a result of insufficient training volume or if the observed decrease is a temporary reduction in performance due to fatigue. The largest reduction in any of the power generation measures over pre-season was reported for RFD 0.1. Given that RFD is likely to have a neurological basis (Cormie, McGuigan and Newton, 2011b) some degree of neural fatigue appears to have occurred over the pre-season phase. This is further evidenced by the increase in RFD at 0.1 s that occurred in the first part of the season despite no substantial increases in power training volume. The absence of significant differences between data collection trials in CK suggests muscle fibre damage is not responsible for reported differences in RFD.

The finding of reductions in RFD 0.1 during pre-season alongside increases in IMTP peak force shows increases in peak force do not necessarily increase the rate at which such force can be expressed. The finding that increases in strength do not improve power output in trained populations is in keeping with previous research (Newton, Kraemer and Hakkinen, 1999). This should be considered by practitioners when planning a periodized approach to maximising power output in rugby union players. In contrast to decreases in RFD 0.1, small increases in RFD 0.2 (6%) occurred over the pre-season phase. It is possible that the greater period of time to develop force within this measure meant it was less influenced by neural fatigue. It is also possible that the increased period of time to develop force allowed for a greater transference of pre-season increases in IMTP peak. An improvement in the quality with a longer time to develop force and a reduction in a quality with the shorter time to develop force is perhaps unsurprising when one considers the focus of resistance training during pre-season was on developing maximum strength and not maximum power (appendix 6).

Small improvements in whole group RFD 0.1 (5%), and relIMTP 0.1 (2.7%) were recorded across the whole competitive season. Maintenance was reported for RFD 0.2(-1.5%) and IMTP 0.2 (0.6%). This suggests two weekly power sessions were sufficient to bring about small improvements or maintenance in RFD throughout the competitive season. Whilst RFD has been identified as an important characteristic in the performance of power based tasks, no previous study has directly examined the change in this characteristic over the course of a pre-season or competitive season in professional rugby union players. It is therefore not possible to compare the finding of this investigation to existing literature.

#### 5.2.4 Jump measures and SSC performance

Whilst concentric only RFD provides useful information regarding the speed at which force can be developed, human movement generally involves the coupling of eccentric, isometric and concentric actions as a part of the SSC (Flanagan and Comyns, 2008, Komi, 2000). Within this study SSC was measured via jump performance. Small whole group reductions in EUR (-2%) occurred over the course of the pre-season phase. The backs also showed reductions in CMJ (3%), and RSI (-5%) during this period. Reductions in CMJ, EUR and RSI for backs appear to be evidence of reduced SSC performance over the course of the pre-season phase (Fowles, 2006, McGuigan *et al.*, 2006). Given that reductions in SSC performance have been identified as potential indicators it appears that some degree of neural fatigue occurred over this phase (Fowles, 2006, Mclean *et al.*, 2010). It could be that as suggested by Argus (2012) a positive power training effect had occurred during the pre-season phase but was masked by fatigue from the overall volume of training performed. The time course of recovery from neuromuscular fatigue and the subsequent expression of such a response in a team sport population is however unclear. It is however also possible that a focus on improving maximum strength and not power within the pre-season period (appendix 6) led to the observed reduction in jump based measures.

The reported reduction or maintenance of jump performance over the course of the pre-season phase is in keeping with previous findings in rugby league and union (Argus *et al.*, 2009, Harris *et al.*, 2008). According to Harris *et al.*, (2008), it is likely that the observed reduction in jump performance is due to fatigue from the large volumes of training performed during the pre-season period. It has been suggested that high volumes of training for multiple components of fitness as in a pre-season phase are likely to compromise power development (Baker, 2001).

In contrast to the findings of this investigation, studies by Gabbett (2005a; 2005b) reported improvements in jump performance following the pre-season phase in rugby league players. In both of the studies by Gabbett (2005a; 2005b) the participants were amateurs and performed two organised training sessions per week. As a result of the far lower overall training volume compared to the present study it is likely that they were subjected to far less fatigue from concurrent training. This has previously been identified as a factor likely to be detrimental to power development (Baker, 2001). O'Connor and Crowe (2007) also reported improved power output following the pre-season phase. However in this study lower body peak power testing was conducted via a 10s maximal cycle sprint. Whilst a valid measure of lower body power output, the minimal use of the SSC in this action means it is unlikely to be affected by neuromuscular fatigue to the same degree as jump based testing (Fowles, 2006).

Small improvements in whole group CMJ (2.5%) and EUR (4.7%) were recorded across the competitive season alongside maintenance in SQJ. Small reductions in RSI (-1.5%) did however occur during this period suggesting some reduction in fast SSC performance took place. Reductions in RSI over the competitive season occurred alongside improvements in IMTP 0.1 (3.7%) and RFD 0.1 (17.8%). It is possible that such reductions in fast SSC performance despite improvements in force production in short periods of time represent existence of neural fatigue. Further research should examine the use of fast SSC measures for detecting neural fatigue over the course of a competitive season.

The finding of maintenance or small improvements in jump performance over the course of the competitive season is in keeping with some of the available research (Argus *et al.*, 2012, Dos Remedios *et al.*, 1995). Previous work examining changes in lower body power over the course of a competitive season has however typically reported maintenance or reduction in jump measures (Argus *et al.*, 2009, Baker, 2001). As previously discussed variations between studies in terms of training and competition exposure as well as subject characteristics and testing methods are likely to explain discrepancies in result between studies.

The jump values reported in this investigation for professional rugby union players are approximately 15-20% lower than those reported in amateur and junior rugby league players by Gabbett (2005a; 2005b). It should however be noted that the studies of Gabbett (2005a: 2005b) employed a jump and reach measurement system. In a further study reporting jump height derived from force plate data in professional rugby league players West *et al.* (2011) reported an average CMJ of 36.5 cm. This is similar to the group mean of 40.7 cm reported here. Comparison of the IMTP data and other jump measures reported here with other work is difficult due to the lack of studies in the contact codes of football using similar assessment techniques.

### 5.2.5 Comparison of overall changes in power performance

Whilst the discussion of change in specific neuromuscular qualities is likely to be of greater relevance to the practitioner than the discussion of overall power performance it is important to look at the combined effect of the changes in neuromuscular characteristics reported here. Taken as a whole the results of this investigation show small decreases or maintenance of power based characteristics over the pre-season phase and small improvements or maintenance of most power based characteristics during the competitive season.

The maintenance of lower body power output reported here over a 33 week competitive season appears to be at odds with the small reduction in power reported by Argus *et al.* (2010) following a 13 week competitive season in New Zealand based players. When the greatly increased UK season length is considered it is perhaps surprising that the English players were able to show more favourable changes in power based characteristics. One of the key differences between the studies which may explain this finding is the frequency of power training employed. In the study of Argus *et al.* (2010) subjects only performed power training once each week whereas in the present study it was included twice weekly. As previously reported, frequency is a key variable in bringing about positive muscular adaptations (Peterson, Rhea and Alvar, 2006) and it seems likely that a frequency of power training greater than once per week is needed to preserve or slightly increase lower body power output.

The failure of this study and others to report large significant gains in power over the competitive season is likely to be due to multiple factors including insufficient training stimulus, neuromuscular fatigue and the training age of the subjects (Argus *et al.*, 2009). During the competitive season the subjects in this study only performed resistance training designed to improve power output twice within each week. It is likely that a higher frequency of power training than this is needed to bring about significant enhancements (Argus *et al.*, 2009). The failure to report large increases in lower body power output in this investigation may also be in part due to frequent matches and training with limited recovery time. It is possible this state would lead to build up of residual fatigue or an 'over-reached' state which will likely lead to a decrement in power performance (Halson and Jeukendrup, 2004). The relatively advanced training age of subjects in this study may also make large increases in power output unlikely (Cormie, McGuigan and Newton, 2011b). It has been previously shown that only small increases in power are likely in elite rugby players, even when time frames comprising multiple seasons are considered (Baker and Newton, 2006, Baker, 2013).

### 5.2.6 Body composition

The likely benefits of increased muscle cross sectional area in terms of force production (Shoepe *et al.*, 2002) have previously been eluded to. Whilst the cross sectional area of the major muscles of the lower body was not assessed directly, FFM was examined in order to gain an understanding of overall changes in muscle mass. Within this investigation an increase of 1.7% in FFM alongside a 1.3% reduction in body mass was reported during the pre-season phase. Following this FFM was maintained (0.5%) whilst body mass showed a small increase

(1.7%) over the competitive season. Favourable changes in body composition over the pre-season period including both reductions in fat mass and increase in FFM have been widely reported within the literature (Argus *et al.*, 2010, Gabbett, 2005b, Holmyard and Hazeldine, 1992, Rogerson *et al.*, 2007). It is likely that the increase in FFM and decrease in body mass reported over the pre-season phase in this investigation are due to the increased volume of training and greater frequency of resistance training taking place within this period. The finding of maintenance in FFM alongside small increases in body mass suggests a small increase in fat mass occurred within the competitive season in the present study. Whilst this is in contrast to the finding of Dos Remedios *et al.*, (1995) in college aged American football players, a lack of available literature regarding changes in body composition in professional rugby union players over a competitive season makes this finding difficult to interpret. It is possible that given the maintenance of body mass is often desirable (Crewther *et al.*, 2009a) and training volumes are reduced, a small gain in fat mass is relatively common over the competition phase of the season in professional rugby players.

### 5.2.7 Positional group

This investigation examined differences between backs and forwards in terms of both physiological characteristics and the change in these physiological characteristics over the course of a whole season. Forwards were found to possess higher scores for IMTP peak, IMTP 0.1 and IMTP 0.2 when compared to backs. Forwards were also found to have higher body mass and FFM than backs. The finding that forwards are heavier and possess higher levels of peak force output and specific power characteristics is in keeping with the available literature (Crewther *et al.*, 2009a, Duthie *et al.*, 2006, McMaster *et al.*, 2013). This investigation also reported that backs possess superior CMJ, SQJ and RSI capabilities. This is also in accordance with previous research (Smart *et al.*, 2014).

Whilst both positional groups experienced similar changes in some physiological characteristics over the whole season there were several areas of difference. Following the pre-season phase the backs reported decreases in all jump measures

(CMJ, SQJ, EUR, RSI) and both IMTP 0.1 and relIMTP 0.1. In the same period forwards also experienced decreases in CMJ, SQJ and EUR but showed maintenance of RSI and improvements in IMTP 0.1 and relIMTP 0.1. In simple terms this appears to show a decrease in force output in very short periods of time both with and without SSC involvement for the backs. Forwards in contrast showed no decrease in fast SSC performance alongside an improvement in one measure of force generation without SSC involvement.  Given the two positional group performed similar training in the pre-season period the reason for these differences is unclear. It is possible that the backs performed more running volume within the pre-season training phase and as a result experienced greater levels of neuromuscular fatigue. It is also possible that a greater volume of high speed running lead to larger decreases in fast SSC performance within the backs group. Whilst backs have been shown to perform larger volumes of high speed running within matches (Roberts *et al.*, 2008) without GPS or time-motion data from pre-season training sessions this suggestion cannot be evaluated. It is possible that backs showed greater decreases in fast SSC performance due to their higher starting RSI scores. These findings appear to suggest the fast SSC activities may be the most appropriate means of detecting neural fatigue in backs. Further research is however needed to examine this suggestion.

This investigation found very little difference between the two positional groups in terms of change in physiological characteristics over the competitive season. Argus *et al.*, (2010) suggested that forwards were more likely to show more favourable changes in strength than backs over the course of the season due to greater exposure to isometric loading through forward specific tasks such as scrummaging and mauling. Whilst it is conceivable that this additional stimulus may aid the maintenance of maximal strength qualities, the quantities of resistance training performed in the present study appear to have led to at least maintenance in both positional groups. The finding of maximal strength improvement in the backs group who were not exposed to scrummaging or mauling suggests that an additional isometric strength stimulus is not needed for maintenance. It is however possible that the greater frequency of sprinting performed by backs in match play (Roberts *et al.*, 2008) provides a maintenance stimulus for force production.

### 5.2.8 Match minutes

Within this investigation increased match exposure did not have any negative effect on improvements in maximal strength. Indeed whole season match minutes were moderately correlated with total percentage increase in IMTP peak and relIMTP peak. Match minutes played in the first part of the season (September to January) were also found to be moderately correlated with total percentage increase in IMTP peak and relIMTP peak. This suggests match play had a positive effect on maximum strength development. Whilst it is possible that the high intensity nature of rugby union match play (Duthie, Pyne and Hooper, 2003) acted as a strength training stimulus this finding could also be due to other factors. It also possible that those players who played more minutes were selected more frequently as they were athletically superior, as has been shown in other contact codes of football (Young *et al.*, 2005) and as a result responded more quickly to strength training. It could also be that these players had higher levels of motivation as a result of more frequent selection.

This investigation found small negative correlations between whole season match minutes and percentage change in RSI, SQJ and both raw and relative IMPT force at 0.1 s. Whilst all of these correlations were small, taken as a whole they do appear to support findings within the literature suggesting that frequent exposure to match play is likely to lead to neuromuscular fatigue (Mclean *et al.,* 2010). From this it is apparent that practitioners must take into account match minutes when planning power development or maintenance strategies.

Match minutes played in the second part of the season (January to April) were found to be moderately correlated with whole season percentage change in CMJ. This relationship was found to be statistically significant. Given that the largest part of the total percentage increase in CMJ scores for the whole season occurred in the second part of the season it is clear how the second half of the season match minutes were able to influence whole season change. Without analysis of individual subject scores and more information regarding their training it is difficult to explain why the significant relationship exists. It is possible that reduced number of games in the second part of the season can explain this finding. It could also be related to lower training motivation within players with low game minutes in this period. However without further information such a suggestion remains speculation.

### 5.3.1 Limitations

This investigation has several clear limitations. Firstly the measured changes in player characteristics were often much smaller than the within group standard deviations. This makes the statistical interpretation of the results reported difficult. This is especially true when one considers that the magnitude of changes in physiological characteristics in elite athletes over multi-season periods is often relatively small (Appleby, Newton and Cormie, 2012, Baker, 2013). The size of the cohort is also a limitation within this investigation. The low number of backs severely limited the statistical power of analyses performed on this group. Furthermore there were insufficient forwards to divide into smaller positional sub categories despite known differences in match movement profiles (Austin, Gabbett and Jenkins, 2011).

This study is also limited by the lack of detailed information provided regarding the volume and intensity of all types of training undertaken over the season. This limits the accuracy of inferences that can be made regarding the basis for changes in physiological characteristics.

### 5.4.1 Further research

Future work should examine other factors that may affect changes in physiological characteristics over the course of a whole season. Further quantification of total work performed by players in both matches and training may provide greater insights into the factors which effect change in strength and power qualities over the course of a season. The widespread use of GPS data within professional rugby represents a means of quantifying both distances covered and the frequency of repeated high intensity efforts (Austin, Gabbett and Jenkins, 2011). Examining such data within the context of changes in strength and power would be of great interest. More detailed analysis of the type of strength periodization followed across a season is also required to assist the practitioner in optimising his approach.

### 5.5.1 Conclusions

Findings from this investigation suggest that professional rugby union players are likely to increase strength and FFM over the pre-season phase. The findings of this investigation and that of Appleby, Newton and Cormie (2012) appear to suggest that increases in FFM are likely to assist in the development of maximal strength. Coaches should therefore consider including work designed to bring about increases in FFM if maximal strength gain is their objective.

Despite increases in strength it appears that lower body power output is likely to be reduced or at best maintained over the course of the pre-season. The findings of this investigation and others suggest that volumes of total work performed and the multiple components of fitness that must be addressed in the pre-season period mean that improvements in lower body power are difficult to achieve. Whilst it is possible that adaptation in power is simply masked by fatigue during pre-season (Argus, 2012) practitioners should take this into account when planning a periodized approach to strength and power development across a full season.

The results of this investigation show that the maintenance of power and strength is possible over the competitive season. Compared to the work of Argus *et al.*, 2010 this study appears to suggest that two resistance training sessions targeting power as opposed to one are needed each week for the maintenance of this quality. The finding within this study that power output was only maintained despite increases in maximal strength is of interest to practitioners. Previous work has shown that increases in maximal strength led to improved power output (Adams *et al.*, 1992, Young and Bilby, 1993). The results of this investigation however appear to support the suggestion that power is a multifaceted characteristic and that several neuromuscular qualities must be trained in experienced athletes in order to maximise it (Cormie, McGuigan and Newton, 2011b).

Within this study it appears that both positional groups show very similar changes in physiological characteristics over the whole season. It is however possible that backs are likely to experience more universal reductions in power based measures when compared to forwards. It appears that fast SSC performance may be the most effective means of monitoring levels of neural fatigue in backs however further research in this area is required. Whilst competitive match play has been previously identified as a factor likely to cause high levels of fatigue it would appear that total match exposure did not have any detrimental effect on muscular strength increases over the course of the season. It does however appear that match exposure is negatively related to power development. In a long term development setting these results appear to suggest that if levels muscular power are to be maximised, players' game time must be controlled or specific physical development windows should be allocated within a competitive season.

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**Appendices**

**Appendix 1: Participant Information sheet**

# Changes in strength and power characteristics over a season in elite English rugby union players

## INFORMATION SHEET FOR PARTICIPANTS

Thank you for your interest in this project. Please read all of the information contained with this sheet before deciding whether or not you wish to participate. If you decide not to take part in this study there will be no disadvantage to you in any way and we thank you for considering this request.

**What are the aims of the project?**

- This project aims to gain a greater understanding of the way in which players maximal levels of strength and power vary over the course of a rugby season.

- The project will investigate the relationship between perceived player wellness and strength and power performance.

- The project also aims to gain a greater understanding of the link between training, playing and injury data and physiological and wellness measures.

This project is being undertaken as part of the requirements for a Master of Science by research degree.

**What type of participants are needed?**

This projects requires elite rugby union players who are part of the Bedford Blues squad 2012-14.

**What will participants be asked to do?**

Should you agree to participate in this project you will be asked to;

Allow the researchers to use data collected about you by the Bedford Blues Strength and Conditioning staff concerning strength and power tracking (through performance data from mid-thigh isometric pull and jump performance tests) wellness and readiness to train, match and training exposure, modifications to your training schedule due to injury, body mass and body composition tracking via skinfold and bioelectrical impedance measures to be used for research purposes. The jump performance tests involve performing 3 different types of jump on either a jump mat or a force plate. The 3 different types of jump are a countermovement jump, a squat jump and a depth jump. Body composition changes will be tracked using the bodpod measuring system.

You should be aware that you can decide not to take part in this project without any disadvantage to yourself of any kind.

**What are the risks of taking part in this study?**

As with all exercise there is a risk of injury. In order to minimise this all testing will be supervised by an accredited Strength & Conditioning coach and you will be required to complete a readiness to exercise questionnaire prior to participation in this study.

**Can participants change their mind and withdraw from the project?**

You may withdraw from the project at any time and without any disadvantage to yourself of any kind.

**What data or information will be collected and how will it be used?**

Results of this project may be published but any data included in published documents will be in no way linked to specific participants. Participants will be given feedback on the specific findings of the study upon its completion. You can request a copy of the results if you so wish.

All data that is collected will be stored securely and only the researchers mentioned on this form will have access to that data. Upon completion of this project any personal information collected will be destroyed except for raw data which will be securely stored for a period of time outlined by the University's research policy.

**What if the participants have any questions?**

If you have any questions about the project now or in the future please feel free to contact either:

Patrick Hogben
Institute of Sport and Physical Activity Research
University of Bedfordshire,
Bedford Campus,
Polhill Avenue,
Bedford,
MK41 9EA

OR

Dr Iain Fletcher
Institute of Sport and Physical Activity Research
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Polhill Avenue,
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MK41 9EA

Telephone: 07843 390183

Email paddy.hogben@beds.ac.uk

**Alternatively, If you would like to speak with someone independent from the research study please contact: Professor Angus Duncan, Secretary to the University Research Ethics Committee, Email: angus.duncan@beds.ac.uk. Telephone: 01582 743473.**

**Appendix 2: Informed Consent Form**

## Changes in strength and power characteristics over a season in elite English rugby union players

### CONSENT FORM FOR PARTICIPANTS

I have read the Information Sheet concerning this project and understand what it is about. All my questions have been answered to my satisfaction. I understand that I am free to request further information at any stage.

I know that:-

1. My participation in the project is entirely voluntary;

2. I am free to withdraw from the project at any time without any disadvantage;

3. Any personal data collected will be destroyed at the conclusion of the project but any raw data on which the results of the project depend will be retained in secure storage for a period of time determined by the university's research policy, after which it will be destroyed;

4. The results of the project may be published but my anonymity will be preserved.

I agree to take part in this project. I am aware of any risks that may be involved and that all information and data collected will be held securely at the University indefinitely.

.................................................................................
...............................
(Signature of participant) Date:

## Appendix 3: PAR-Q Form

### PAR-Q

1. Have you ever been told by a doctor that you have a heart condition and advised only to participate in physical activity by your doctor?

2. Do you experience any chest pains when you participate in physical activity?

3. Have you recently experienced any chest pains whilst not participating in physical activity?

4. Do you ever lose consciousness?

5. Do you ever lose your balance as a result of dizziness?

6. Do you have any problems with you bones and joints that could cause further problems if you participate in physical activity?

7. Are you aware of any other reasons as to why you should not participate in physical activity?

Can you answer **Yes** to any of questions 1-7? Please circle your response below:

Yes No

Name: Signature: Date:

**Appendix 4: BLOOD ANALYSIS – Participant Screening Form**

Please read the following:

a. Are you suffering from any known active, serious infection?
b. Have you had jaundice within the previous year?
c. Have you ever had any form of hepatitis?
d. Have you any reason to think you may be HIV positive?
e. Have you ever been involved in intravenous drug use?
f. Are you a haemophiliac?
g. Is there any other reason you are aware of why taking blood might be hazardous to your health?
h. Is there any other reason you are aware of why taking your blood might be hazardous to the health of the technician?

Can you answer **Yes** to any of questions a-h? Please tick your response in the box below: Yes No

Small samples of your blood (from finger or earlobe) will be taken in the manner outlined to you by the qualified laboratory technician. All relevant safety procedures will be strictly adhered to during all testing procedures (as specified in the Risk Assessment document available for inspection in the laboratory).

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| I declare that this information is correct, and is for the sole purpose of giving the tester guidance as to my suitability for the test.<br>Name ……………………………………… |

Signed ……………………………………………

Date ……………………………………………

If there is any change in the circumstances outlined above, it is your responsibility to tell the person administering the test immediately.

The completed Medical Questionnaire (Par Q) and this Blood Sampling Form will be held in a locked filing cabinet in the Department of Sport and Exercise Science laboratories at the University for a period of one-three years. After that time all documentation will be destroyed by shredding.

## Appendix 5: Tables summarising literature discussed within the literature review

Table 6.1 Studies showing changes in maximal strength, power and body composition over a pre-season phase in contact codes of football.

| Author | Participants | Study duration and measuring points | Measures | Results |
|---|---|---|---|---|
| Argus *et al.*, 2010 | 33 elite male rugby union rugby union players. | Pre and post a 4-week pre-season training phase. | Strength: Lower body, box squat 1RM. Upper body, bench press 1RM.<br>Power: Lower body, Smith machine jump squat at 55% and 60% of box squat 1RM. Upper body, Smith machine bench throw at 50% and 60% of bench press 1RM. Peak power was recorded for each exercise<br>Body composition: 8 site skinfold measure. | Strength: Improvement in box squat 1RM of 11.3% $^{\times}$ and bench press 1RM of 11.1%$^{\times}$.<br>Power: Reduction in jump squat power output of -5.2% $^{\times}$ and bench throw power output of 5.6% $^{\times}$.<br>Body composition: Sum of 8 skinfolds reduced by -11.5%. |
| Gabbett, 2005a | 52 amateur rugby league players and 16 men in a non-exercise control group. | Subjects were tested during an off-season training block and following at least 8 weeks of a pre-season training block. The exact time between testing sessions is not reported. This assessment was part of an investigation a 9 month training cycle. Subjects were tested 4 times in this period. Testing took place in the off-season, pre-season, mid-season and end of season. | Strength: Not measured.<br>Power: Vertical jump via jump and reach system. Speed through 10, 20 ad 40m sprints.<br>Body composition: 7 site skinfold measures. | Power: Vertical jump increased by 5.7%. Speed testing performance remained unchanged.<br>Body composition: Sum of 7 skinfolds decreased by 7%*. |

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| Gabbett, 2005b | 36 junior amateur rugby league players and 9 men in a non-exercise control group | Subjects were tested during an off-season training block and again following at least 8 weeks of a pre-season training block. The exact time between testing sessions is not reported. This assessment was part of an investigation a 9 month training cycle. Subjects were tested 4 times in this period. Testing took place in the off-season, pre-season, mid-season and end of season. | Strength: Not measured.<br>Power: Vertical jump via jump and reach system. Speed through 10, 20 ad 40m sprints.<br>Body composition: 7 site skinfold measures | Power: Vertical jump increased by 6.2%*. Speed testing performance remained unchanged.<br>Body composition: Sum of 7 skinfolds decreased by 9.3%*. |
| Harris *et al.*, 2008. | 18 elite level rugby league players. Split into 2 training intervention groups (training at Pmax (n=9) vs training at 80% 1RM (n=9)). | Pre and post a 7 week training period during the pre-season period. | Strength: Machine concentric only hack squat.<br>Power: Machine concentric only jump squat, 10m an 30m sprint times.<br>Body composition: Not measured. | Strength: Increases (11% Pmax and 15% in 80% 1RM group)<br>Power: Decreases (-17%ˣ Pmax and -6%ˣ 80% 1RM group) in machine jump squat power output.<br>Small decreases in 10m (-1.3%ˣ Pmax and -2.9%ˣ in 80% 1RM group) and 30m sprint times (-1.2%ˣ Pmax and -1.9%ˣ in 80% 1RM group. |
| O'Connor and Crowe, 2007. | 30 elite level rugby league players split into 3 groups in a dietary intervention. (HMB (n=11) vs HMB-CR (n=11) vs Control (n=8)). | Pre and post a 6 week training period during the pre-season period. | Strength: Lower body, Deadlift 3RM. Upper body, bench press 3RM.<br>Power: Peak power in a 10s maximal cycle ergometer test.<br>Body composition: 8 site skinfold measure. | Strength: Increases in deadlift 3RM (11%* control, 13%* HMB and 11%* HMB-CR). Increases in bench press 3RM (3%* control, 5%* HMB, 4%* HMB-CR).<br>Power: increases in peak power output (3%* control, 4%* HMB, 4%* HMB-CR). |

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| | | | | Body composition: decreases in sum of skinfold scores (3%* control, 8%* HMB, 7%* HMB-CR). |
| Rogerson *et al.*, 2007 | 22 elite male rugby league players. Split into 2 dietary intervention groups (Tribulus terrestris (n=11) vs placebo (n=11). | Pre and post 5 weeks of training during the pre-season period. | Strength: Lower body, deadlift 2RM. Upper body, bench press 2RM.<br>Power: Not measured<br>Body composition: Measured FFM via multi frequency bio electrical impedance. | Strength: Improvements in deadlift 2RM (21%* tribulus terrestris and 17%* control), Improvements in bench press 2rm scores (14%* tribulus terrestris and 11%* control). Significant increases in FFM were reported for both groups. |

Pmax, load at which mechanical power output is maximized. RM, repetition maximum. HMB, β-hydroxy-β-methylbutyrate. HMB-CR, β-hydroxy-β-methylbutyrate+ creatine monohydrate. ˣ, significance not reported. *, $p \leq 0.05$

Table 6.2 Studies showing changes in maximal strength, power and body composition over a competitive season in contact codes of football.

| Author | Participants | Study duration and measuring points | Measures | Results |
|---|---|---|---|---|
| Argus *et al.*, 2009 | 32 professional rugby union players. | Subjects were tested up to 5 times over the course of a 13 week competitive season. | Strength: Lower body, box squat 1RM. Upper body, bench press 1RM.<br>Power: Lower body, Smith machine jump squat at 55% and 60% of box squat 1RM. Upper body, Smith machine bench throw at 50% and 60% of bench press 1RM. Peak power was recorded for each exercise<br>Body composition: Not reported. | Strength: Improvement in box squat 1RM of 8.5% ×. Decrease in bench press 1RM of -1.2%×.<br>Power: Reduction in jump squat peak power output of -3.3% × and bench throw power output of -3.4% ×. |
| Argus *et al.*, 2012 | 18 high level rugby union players (semi-professional and professional). Players were split into a strength-power (n=9) or a speed-power (n=9) training group. | Pre and post a 4 week period during at the start of a competitive season. | Strength: Lower body, back squat 1RM was measured in a smaller group (n=12).<br>Power: Pmax was calculated for all of; Body weight CMJ, SQJ, and DJ (RSI calculated), 50kg CMJ and 50kg SQJ.<br>Body composition: Not measured. | Strength: lower body, back squat 1RM increased by 4.8%.<br>Power: body weight CMJ increased by 1.6% (strength-power) and 0.8% (speed-power).Body weight SQJ decreased by -1.4% (strength-power) and remained unchanged (0.4%: speed-power). Pmax in weighted CMJ increased by 12% (strength-power) and 3.1% (speed-power). Pmax in weighted SQJ increased by 11% (strength-power) and 4.4% (speed-power). RSI remained unchanged (0.8%) |

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| | | | | in strength-power group and increased (3.4%) in the speed power group. |
| Baker, 1998 | Professional Rugby Union players. | Not stated | Strength: Upper body, Bench press 1RM.<br>Power: Not measured.<br>Body composition: Not measured | Strength: 2%* improvement in bench press 1RM |
| Baker, 1998 | Professional Rugby League players | 22 weeks | Strength: Lower body, full back squat 1RM, upper body, bench press 1RM.<br>Power: Not measured<br>Body composition: Not measured | Strength: Lower body, 3%* improvement in full squat 1RM. Upper body, 4%* increase in bench press 1RM |
| Baker, 2001. | 14 professional rugby league players and 15 college aged rugby league players. | Professional rugby league players were tested pre, post and twice during a 29-week competitive season (lower body power was only tested pre and post). College aged players were tested pre, mid and end of season over a 19 week competitive season. | Strength: Upper body, Bench Press 1RM, lower body maximum strength was not measured.<br>Power: Lower body, Pmax was obtained for jump squats using resistances of 40,60,80 and 100kg. Upper body, Pmax was obtained for Bench throw using resistances of 40,50,60,70 and 80kg.<br>Body composition: Not measured. | Strength: professional players reported decreases of 1%, college aged players showed improvements of 3%* in bench press 1RM.<br>Power: Lower body, jump squat Pmax showed small decrease in professional players (-1.3%) and a 4% increase in college aged players. |
| Dos Remedios *et al.*, 1995 | 19 college American football players. The group was split into linemen (n=11) and non linemen (n=8). | Subjects were tested pre and post a 10 week competitive season. | Strength: Lower body, assessed via a hip sled drag, Upperbody assessed via bench press 1RM. | Strength: Lower body, decreases in Hip-sled load of linemen (-4%) and non linemen (-1%). Upper body, increases in bench press 1RM of 21%* in linemen and |

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| | | | Power: Vertical jump performance via a jump and reach system.<br>Body composition: measured by a 7 site skinfold measure. | decreases of -3% in non linemen.<br>Power: Vertical jump decreased in linemen (-4%) and was maintained in non linemen (0%).<br>Body composition: % body fat decreased in both groups. |
| Fleck and Kraemer, 1987 | College aged American football players | Subjects were tested pre and post a competitive season of 14 weeks. | Strength: Lower body, assessed via back squat 1RM and leg press 1RM. Upper body assessed via bench press 1RM. | Strength: Lower body, back squat and leg press 1RM were unchanged. Upper body, bench press 1RM was maintained. |
| Gabbett, 2005a | 52 amateur rugby league players and 16 men in a non-exercise control group | Subjects were tested 4 times over the course of a 9 month training cycle. Testing relating to the competitive season took place at approximately the begining, mid point and end of the competitive season. The competitive season duration was approximately 22 weeks. | Strength: Not measured.<br>Power: Vertical jump measured via jump and reach system. Speed through 10, 20 ad 40m sprints.<br>Body composition: 7 site skinfold measures | Power: Vertical jump decreased by -5% $^{\times}$. Speed testing performance remained unchanged.<br>Body composition: Sum of 7 skinfolds increased from pre-season scores by 10% $^{\times}$ over the course of the competitive season.<br>Reductions in training loads and increases in match intensity and injury rate were reported towards the end of the season. |
| Gabbett, 2005b | 36 junior amateur rugby league players and 9 men in a non-exercise control group. | Subjects were tested 4 times over the course of a 9 month training cycle. Testing relating to the competitive season took place at approximately the beginning, mid-point and end of the competitive season. The | Strength: Not measured.<br>Power: Vertical jump measured via jump and reach system. Speed through 10, 20 ad 40m sprints.<br>Body composition: 7 site skinfold measures | Power: Vertical jump performance was maintained (-0.7% $^{\times}$).<br>Body composition: Sum of 7 skinfolds scores were maintained (change: -0.7% $^{\times}$). |

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|---|---|---|---|---|
| | | competitive season duration was approximately 22 weeks. | | Reductions in training load as well as match intensity and overall match load were reported as the competitive season progressed. |
| Hoffman and Kang, 2003. | 53 NCAA division III college American football players. | Subjects were tested pre and post a 12 week competitive season, | Strength: Lower body, back squat 1RM, Upper body, bench press 1RM.<br>Power: Not measured<br>Body composition: Not measured. | Strength: lower body, 5%* improvements in squat 1RM. Upper body, -1% reduction in bench press 1RM. |
| Legg and Burnham, 1999. | 59 College aged American football players. | Subjects were tested pre, mid-season and post a 10 week competitive season. | Strength: Bilateral shoulder abduction strength was measured using a portable strain gauge device.<br>Power: Not measured<br>Body composition: Not measured. | Strength: declines in maximum strength scores of 28%* were reported. |
| Schneider *et al.*, 1998 | 28 college aged American football players. The group was made up of 17 line men and 11 non line men. | Pre and post a 16 week competitive season. | Strength: Lower body, dominant leg isokinetic dynamometry (leg extension), Upper body, Bench press 10RM and isokinetic dynamometry (shoulder abduction).<br>Power: Vertical jump via jump and reach system.<br>Body composition: Not measured. | Strength: Leg extension peak torque increased by approximately 4% in both line men and non-linemen.<br>Bench press decreased by -8%* in both linemen and non-linemen. Shoulder abduction decreased by -6.3% in linemen and by -11.5%* in non-linemen.<br>Power: Vertical jump decreased by -4.6%* in non-linemen and -2.8% in linemen. |

Pmax, load at which mechanical power output is maximized. RM, repetition maximum. ˣ, significance not reported. *, $p \leq 0.05$

Table 6.3 Studies showing changes in maximal strength, power and body composition over a multi-season time period in contact football codes.

| Author | Participants | Study duration and measuring points | Measures | Results |
|---|---|---|---|---|
| Appleby, Newton and Cormie, 2012 | 20 professional rugby union players. The group was split into forwards (n=12) and backs (n=8). (19 completed al UB and 11 all LB). | Subjects were tested pre, at the midpoint and post 2 years of training. | Strength: Lower body, back squat 1RM. Upper body, bench press 1RM.<br>Power: Not measured.<br>Body composition: 7 site skin fold measure. | Strength: Lower body, back squat 1RM increased by 10.8%. Upper body, bench press 1RM increased by 11.5%*.<br>Body composition: Sum of 7 skinfolds decreased by 3.9% |
| Baker, 2013. | 6 professional rugby league players. | Subjects were tested annually across a 10 year period. Testing results for 1 year are not reported. | Strength: Upper body, bench press 1RM.<br>Power: Upper body, bench throw Pmax using 40,50,60,70 and 80kg.<br>Body composition: Not measured. | Strength: Upper body, bench press increased by 22.3%<br>Power: Upper body, bench throw Pmax increased by 22.3%. |
| Baker and Newton, 2006. | 12 professional rugby league players. Subjects split into a more experienced, older elite group (n=6) and a younger, less experienced group subelite (n=6). | Subjects were tested pre, post and at the mid-point of a 4 year period of rugby league specific resistance training. | Strength: Upper body, bench press 1RM.<br>Power: Upper body, bench throw Pmax using 40,50,60,70 and 80kg.<br>Body composition: Not measured. | Strength: Upper body, bench press increased by 14.3%* in the group as a whole, 6% $^{\times}$ in the elite group and 23.9% $^{\times}$ in the subelite group.<br>Power: Upper body, bench throw Pmax increased by 13.9%* in the group as a whole, 5% $^{\times}$ in the elite group and 24.9% $^{\times}$ in the subelite group.<br>. |
| Baker and Newton, 2008 | 6 professional rugby league players. | Subjects were tested pre and post a 4 year period of rugby league specific resistance training. | Strength: Lower body, full back squat 1RM.<br>Power: Lower body, Jump squat Pmax using weighted | Strength: Lower body, full back squat 1RM increased by 14.1%*. |

| | |
|---|---|
| jump squats at 40, 60, 80 and 100kg.<br>Body composition: Not measured. | Power: Lower body, jump squat Pmax increased by 13.3%*.<br>Body mass increased by 3.1% |

Pmax, load at which mechanical power output is maximized. RM, repetition maximum. $^{\times}$, significance not reported. *, $p \leq 0.05$

**Appendix 6: Season Periodization Outline**

Table 6.4 Season outline showing fixture schedule and training phases.

| Week beginning | Season week | Phase | Other |
|---|---|---|---|
| $3^{rd}$ June/$10^{th}$ June | Off-season week 1+2 | 2 week rest | Start Off season |
| $17^{th}$ June/$24^{th}$ June | Off-season week 3+4 | | |
| $1^{st}$ July/$8^{th}$ July | Off-season week 5+6 | 4 week off season prep block | |
| $15^{th}$ July | Pre-season week 1 | | Data Collection 1 |
| $22^{nd}$ July | Pre-season week 2 | Maximum STR 1 | |
| $29^{th}$ July | Pre-season week 3 | | |
| $5^{th}$ August | Pre-season week 4 | Down load week | |
| $12^{th}$ August | Pre-season week 5 | | Warm up game 1 |
| $19^{th}$ August | Pre-season week 6 | Maximum STR 2 | Warm up game 2 |
| $26^{th}$ August | Pre-season week 7 | | Warm up game 3 |
| $2^{nd}$ September | Pre-season week 8 | Down load week 2 | Data Collection 2 |
| $9^{th}$ September | League game 1 | | |
| $16^{th}$ September | League game 2 | Power Development 1 | |
| $23^{rd}$ September | League game 3 | | |
| $30^{th}$ September | League game 4 | Down load week 3 | |
| $7^{th}$ October | Cup game 1 | | |
| $14^{th}$ October | Cup game 2 | Maximum STR 3 | |
| $21^{st}$ October | League game 5 | | |
| $28^{th}$ October | League game 6 | | |
| $4^{th}$ November | League game 7 | Power Development 2 | |
| $11^{th}$ November | League game 8 | | |
| $18^{th}$ November | League game 9 | Down load week 4 | |
| $25^{th}$ November | League game 10 | | |
| $2^{nd}$ December | Cup game 3 | Maximum STR 4 | |
| $9^{th}$ December | Cup game 4 | | |
| $16^{th}$ December | No game | | |
| $23^{rd}$ December | League game 11 | Power Development 3 | |
| $30^{th}$ December | League game 12 | | |
| $6^{th}$ January | Cup game 5 | Down load week 4 | Data Collection 3 |
| $13^{th}$ January | Cup game 6 | | |
| $20^{th}$ January | League game 13 | Maximum STR 5 | |
| $27^{th}$ January | League game 14 | | |
| $3^{rd}$ February | League game 15 | | |
| $10^{th}$ February | No game | Power Development 4 | |
| $17^{th}$ February | No game | | |
| $24^{th}$ February | League game 16 | Down load week 5 | |
| $3^{rd}$ March | League game 17 | | |
| $10^{th}$ March | League game 18 | Maximum STR 6 | |
| $17^{th}$ March | League game 19 | | |
| $24^{th}$ March | League game 20 | | |
| $31^{st}$ March | No game | | |
| $7^{th}$ April | League game 21 | Power Development 5 | Data Collection 4 |
| $14^{th}$ April | League game 22 | | |
| $21^{st}$ April | League game 23 | | End of Season |

## Appendix 7: Change in subject FFM, RSI, EUR and IMTP scores

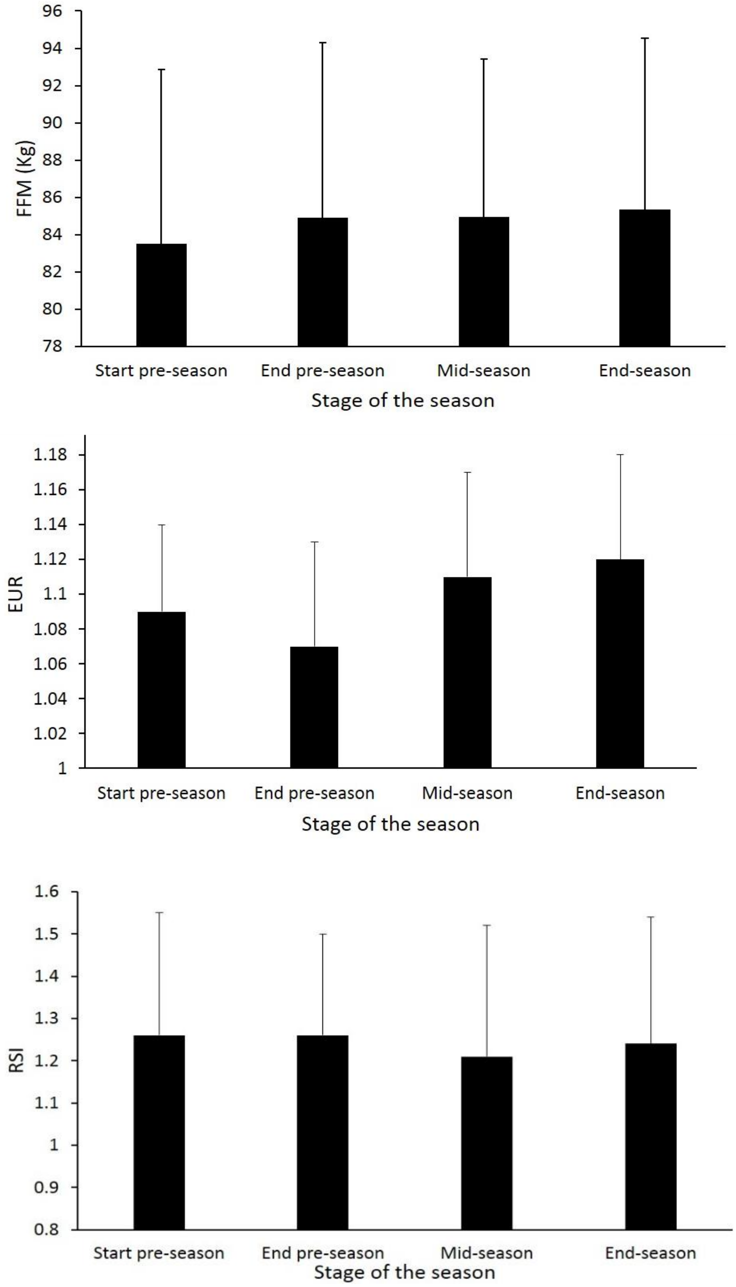


Figure 5.1 Change in whole group FFM, EUR and RSI scores over the course of the season.
Note; FFM, fat free mass; RSI, reactive strength index; EUR, eccentric utilisation ratio.

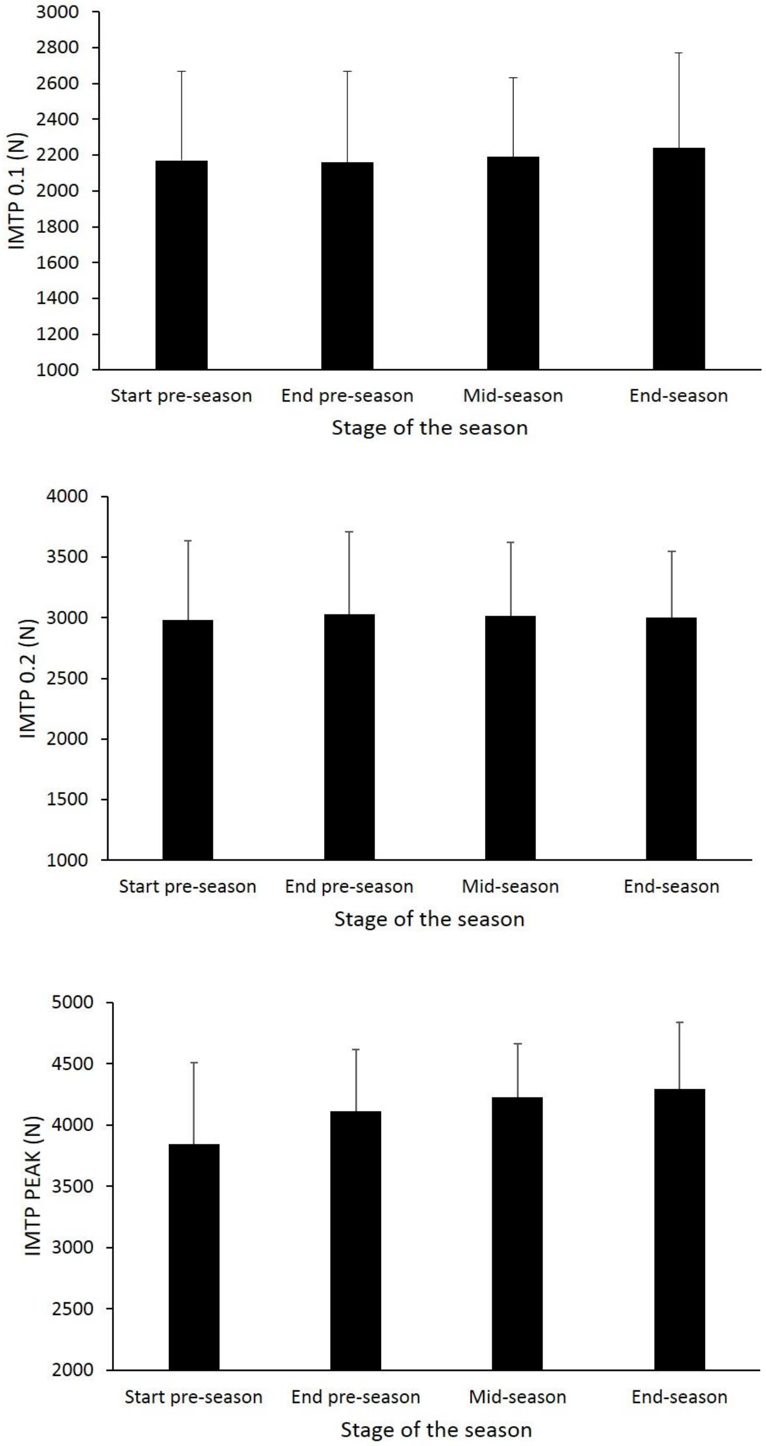


Figure 5.2 Change in whole group raw IMTP scores over the course of the season. Note; IMTP 0.1, raw Isometric mid-thigh pull force 0.1s; IMTP 0.2, raw Isometric mid-thigh pull force 0.2s; IMTP PEAK, raw Isometric mid-thigh pull peak force.